2015 年臺灣國際科學展覽會
優勝作品專輯

作品編號　120001

參展科別　環境科學

作品名稱　奈米鑽石性能對於重金屬吸附之應用

得獎獎項　大會獎：二等獎

美國 ISEF 正選代表：美國第 66 屆國際科技展覽會

推薦參加英語測驗之指導教師

就讀學校　臺北市立建國高級中學

指導教師　鄭淑芬、譚利亞

作者姓名　夏志豪

關鍵字　奈米鑽石、重金屬離子、吸附

作者簡介

夏志豪，今年為建中高二學生，16 歲，從小學到目前高中階段皆從事科學研究，故可謂:科展占滿童年的實例。回首往年，國小第一次從事不同「溶液」(果汁…等)的導電度顯示方式，當時，即是 LED 商品的首次接觸。國中，即開始對重金屬汙染偵測與土壤整治實驗利用 LED 與積體電路作分析，高中並慢慢地轉向純粹對於源頭水溶液進行偵測的分析，高一時，利用水溶液的電阻變化作定性與定量分析。而，現在的我，一位高二學生，不斷尋找大學端與中研院資源，增廣見聞，感謝教授及台大與中研院的協助，使我如願得到關於處理重金屬汙染的新材料分析結果。

如第一段所述，得知化學領域除了物化(理論)尚無深入探討外，其他皆有機會接觸。如今，我已下定決心念化學，更希望能於大學之前將物化軌域與其方程式稍有了解，讓自己對於化學領域選擇有更明確的答案。萬分感謝!

奈米鑽石性能對於重金屬吸附之應用

摘　　要

奈米鑽石之多官能基、介面電位負值(PH=7時)…等性質使本組考慮其吸附重金屬離子之可行性。本研究目的在於利用奈米鑽石吸附重金屬離子及探討重複利用性。

將硝酸鉛、鋅、鎳、銅、鈷與鐵離子及鍺離子水溶液配製奈米鑽石混合懸浮液。本實驗利用共扼焦顯微鏡了解奈米鑽石之生物共生與吸附特性。於重金屬吸附上運用LM324系統、及ICP-MS測量溶液濃度， 且用SEM觀察表面。

研究結果顯示，奈米鑽石具優越吸附離子能力，吸附前後奈米鑽石表面在巨觀與表面微觀上有顯著改變；且再利用性極佳，可利用硝酸置換出金屬離子。故奈米鑽石應可作為具再利用性之吸附材料。

Application of Nanodiamonds Characteristic on Heavy Metal Adsorption

Abstract

Nanodiamond (ND) has superior adsorption characteristics, biocompatibility, abundant functional group and countless terminal points originating from the diamonds' sp^3 orbitals, making our research term considering the possibility of heavy metal adsorption.

The main experiment was focus on the nanodiamonds' adsorption characters. On bio aspect, we used confocal microscope to observe the changing on the algae. We also assumed that nanodiamond has the ability to adsorb heavy metal ions. With the dispersion of nanodiamond in solutions containing Lead (Pb^{2+}), Zinc (Zn^{2+}), Cobalt (Co^{2+}), Iron (Fe^{3+}), Copper (Cu^{2+}), Nickel (Ni^{2+}) and some complexes aqueous solution, we discovered instantaneous sedimentations of compounds from nanodiamond and metal ions. We used LM324 system to measure the conductivity of our samples to reflect its' contents after the addition of solutions containing metal ions. We also used SEM to scan the surface of nanodiamond precipitates before and after reactions.

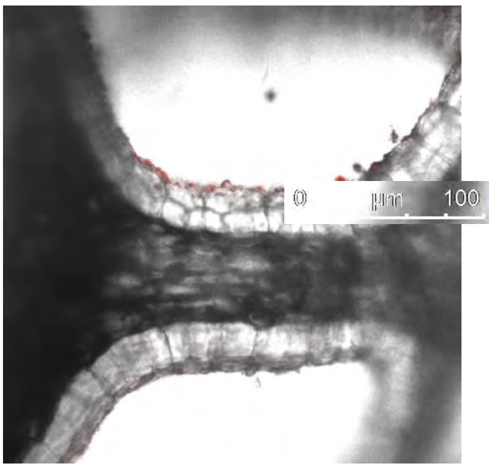
Our results show that nanodiamond has superior adsorption capability of metal ions. The SEM pictures show significant changes on the surface of nanodiamond after compounding with metal ions. With the addition of nitric acid, the metal ions will be dissolved. This makes it possible that nanodiamond can be re-used as an effective metal removal agent.

一、 前言

(一) 研究動機

新聞報導常出現重金屬汙染課題。各地工廠不定時排放重金屬離子廢液致使農田汙染，其嚴重性亦成為世界憂患。近來，綠色化學的概念盛行，尤在美洲地區極為重視，透過課程對其十二個原則了解，深刻體會幾點:無毒、抓害、監控、環境回復…等的環境保育觀念。

近年螢光奈米鑽石(以下簡稱FND)注入動物細胞追蹤研究如火如荼展開。本組在先前從事FND與黃花狸藻的追蹤研究中，觀察到狸藻外部之吸附情形【圖1】，推想FND可能有吸附重金屬離子之用。於先前科展，本組即研究簡易重金屬汙染監測法，利用水溶液內電導度的變化，做為重金屬離子濃度指標、快速分辨重金屬離子種類。本次實驗結合上述的研究結果，進一步運用奈米鑽石材料於重金屬環境整治上之研究。



【圖 1】在黃花狸藻上的奈米鑽石沉澱

(二)研究目的

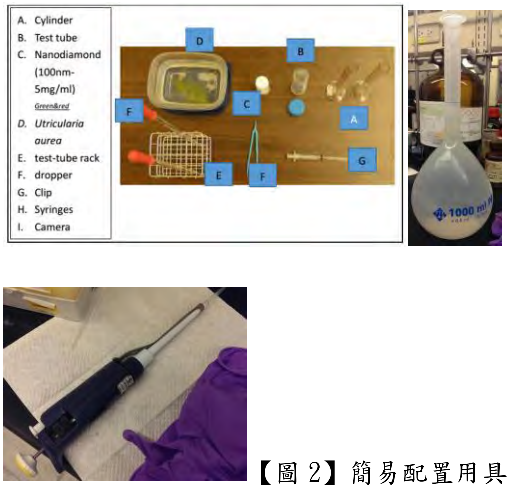
1. 以共扼焦顯微鏡的顯像探討黃花狸藻(*Utricularia aurea*)吸附 FND 的功能。
2. 研究 ND 吸附重金屬離子的效率。
3. 研究吸附重金屬後 ND 表面的結構。
4. 研究重複使用 ND 以吸附重金屬離子的可行性。

二、研究方法與過程

(一)研究設備與藥品

1. 研究設備

1. 配置用具【圖 2】
2. *Utricularia aurea*
3. 壓克力裝置【圖 3】
4. 共扼焦顯微鏡【圖 4】
5. 離心機(10000 轉)【圖 5】
6. 電子秤(小數點後四位)【圖 6】
7. 震盪器【圖 7】
8. SEM【圖 8】
9. ICP-MS【圖 9】
10. 標準瓶【圖 10】



【圖 2】簡易配置用具

【圖 3】壓克力裝置

(箱、白金片及相關電路)

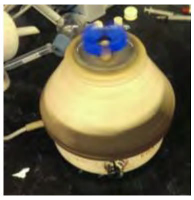
規格:

1.5cm*4cm*2.5cm

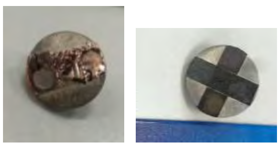
【圖 4】confocal microscope and sample

【圖 7】振盪器與被震盪之奈米鑽石溶液

【圖 6】electronic weight



【圖 5】centrifugation



【圖 8】SEM 樣本(右:碳膠)

【圖 9】標準瓶

【圖 10】ICP-MS

2. 研究藥品

1. Lead Nitrate【圖 11-①】
2. Copper Nitrate【圖 11-②】
3. Nickel Nitrate【圖 11-③】
4. Zinc Nitrate【圖 11-④】
5. Cobalt Nitrate【圖 11-⑤】
6. Iron Nitrate【圖 11-⑥】
7. Ammonia (NH_4OH)
8. 螢光奈米鑽石(Red & green)【圖 12】
9. 奈米鑽石固體(-COOH【圖 13-①】)
10. 奈米鑽石固體(未酸洗【圖 13-②】)
11. 藻類培養水
12. 標準溶液【圖 14】(Zn, Cu, Pb, Fe , Co and Ni)
13. 二次蒸餾純水

【圖 13-①】

ND-COOH

【圖 13-②】

ND (No

【圖 12】FND

【圖 14】Standard solution

【圖 11】Solute

(二) 研究方法與系統概述

1. 文獻探討

(1) The properties and applications of nanodiamonds【註 6】

於本篇文獻中清楚了解奈米鑽石製造過程、特性及其應用方面之推展。係因此篇文章(p.16)圖片提及奈米鑽石官能基的特性，鑑於許多有機官能基離子具孤電子對且該分子的介面電位為負之特質，發想關於錯離子產生的問題與討論。亦因其中提及生物共生性介紹，故本實驗提出生物共生性研究與討論。

(2) 居禮夫人的寶石:螢光奈米鑽石【註 4】

此篇對螢光奈米鑽石有詳盡解說與特徵提供，對初始實驗黃花狸藻藻體奈米鑽石追蹤具開導作用。

(3) 水生開花食蟲植物絲葉狸藻捕蟲囊構造及共質體運輸【註 2】

在理解此篇時，得到黃花狸藻的相關實驗記錄與觀察重點，是為本次實驗之開導。

(4) 利用 IMS 即時顯示系統建立資料庫，在重金屬汙染監測上之應用【註 3】　本組透過此篇方式進行更正與改良(詳請見討論一)用以測試步驟二之導電率檢測法。

(5) 奈米粒子對細胞與生物之毒性及其分布【註 5】
由其中議題及奈米鑽石，本組隊其結果產生毒性探討，並做相關查詢與實驗。

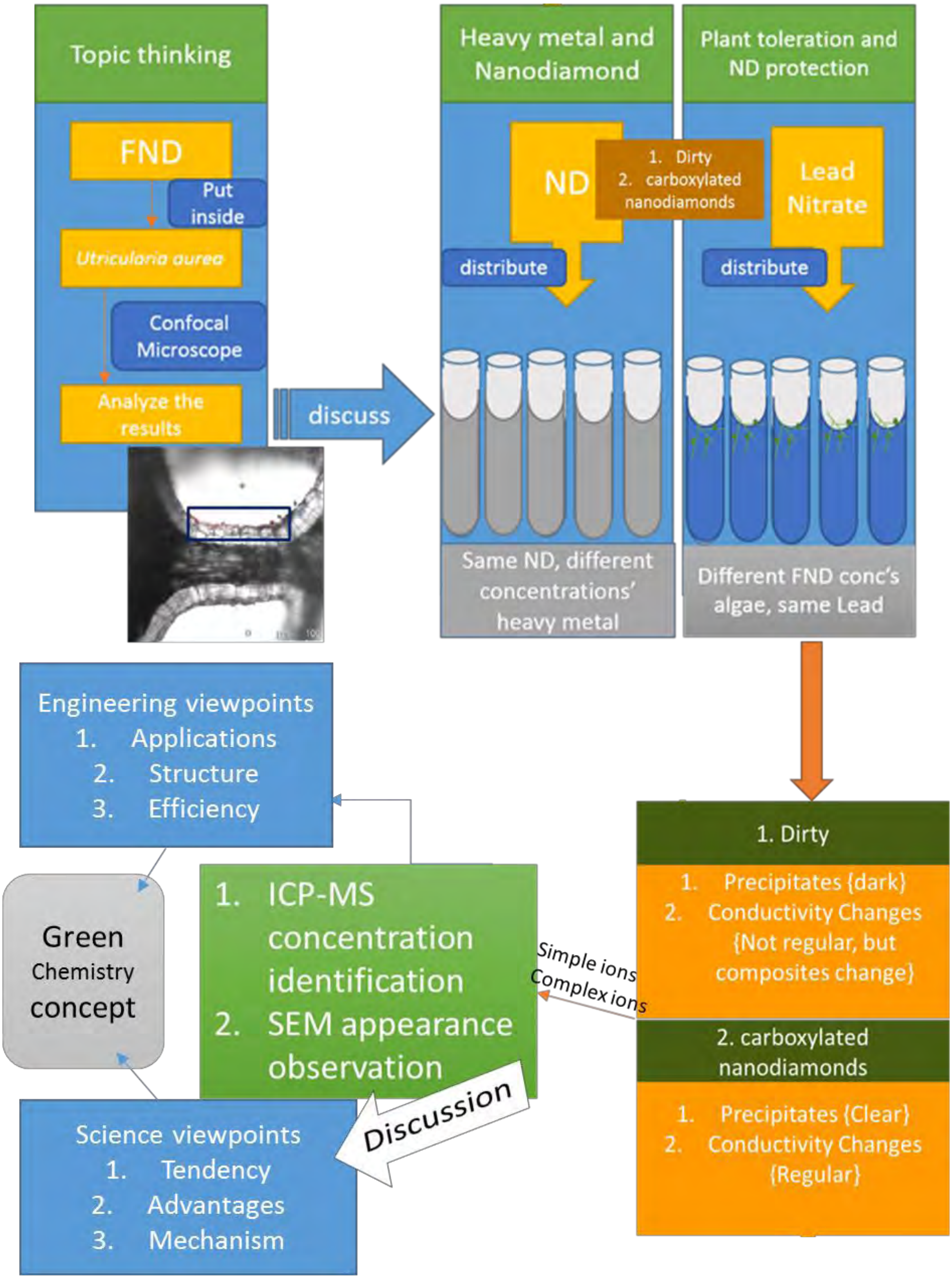
(6) 應用吸水高分子螯合重金屬離子及奈米銀的製備【註 1】
對其無法吸收重金屬錯合物之問題並觀察本組研究成果。

2. 研究方向概述

(1) 文字敘述

先以 FND 來進行追蹤黃花狸藻，透過共扼焦顯微鏡及肉眼觀察並討論未來方向，提出兩點:一、透過奈米鑽石特性及觀察結果直接進行不同濃度硝酸鉛水溶液及植物知吸附與保護作用。二、直接將等量奈米鑽石放入，並從事奈米鑽石與重金屬的吸附與濃度關係。後經第一階段實驗數據得知奈米鑽石的加入確實對整體溶液造成影響，但當時尚未有規律性的結果。故第二階段，本組操作離心機以觀察去除奈米鑽石對本組之影響後前後數據差異。其後即以酸洗後的奈米鑽石來做相關實驗，並指出關於不同重金屬離子差異與分別及討論錯離子化合物的吸附關係。透過成果再討論於科學與工程利用上的重要指標並追溯回綠色化學議題。

(2) 圖像表示


Topic thinking
FND
Put inside
Utricularia aurea
Confocal Microscope
Analyze the results
discuss
Heavy metal and Nanodiamond
ND
1. Dirty
2. carboxylated nanodiamonds
distribute
Same ND, different concentrations' heavy metal
Plant toleration and ND protection
Lead Nitrate
distribute
Different FND conc's algae, same Lead
1. Dirty
1. Precipitates {dark}
2. Conductivity Changes {Not regular, but composites change}
2. carboxylated nanodiamonds
1. Precipitates {Clear}
2. Conductivity Changes {Regular}
Simple ions
Complex ions
1. ICP-MS concentration identification
2. SEM appearance observation
Discussion
Engineering viewpoints
1. Applications
2. Structure
3. Efficiency
Green Chemistry concept
Science viewpoints
1. Tendency
2. Advantages
3. Mechanism

(三) 研究步驟

1. 植物取得、養殖及 ND 與 FND 溶液配製

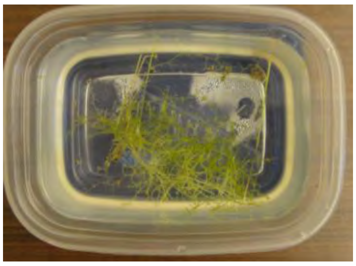
(1) 植物取得

A. 透過【註 3】文獻之詳盡介紹，對黃花狸藻捕蟲囊之結構與方向興趣增長。

B. 在花市與賣水生植物的阿姨購買兩株黃花狸藻。

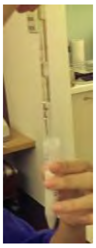
(2) 一般養殖(實驗前)【圖 15】

A. 以自來水養殖即可。



【圖 15】Algae

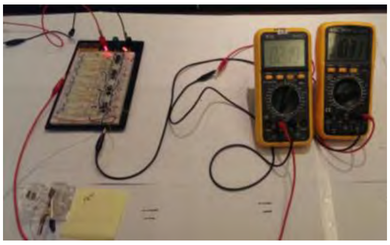
(3) ND 與 FND 溶液配製【圖 16】



A. 以電子秤秤重。

B. 加水並放入超音波震盪器 5 分鐘以將奈米鑽石聚集打散。

【圖 16】配製



【圖 17】LM324 檢測儀

2. 導電率測試【圖 17】

(1) 將一個長、寬、高為 4、1.5、2.5 公分之壓克力箱加入帶測溶液。

(2) 以 LM324 積體電路對其電壓與電流測量，並透過 Excel 計算電阻與電導率，並繪表討論結果。

3. 螢光奈米鑽石對植物之顯像分析

(1) 紅色螢光

【圖 18】溶液與植株生長環境

A. 將步驟一所配製之紅色奈米螢光鑽石溶液取出並稀釋為以下濃度: 125 µg/ml, 100 µg/ml, 75 µg/ml, 50 µg/ml, 25 µg/ml, 5 µg/ml。【圖 18】

B. 取出植株並放入溶液中。【圖 19】

C. 取 125 μg/ml, 5 μg/ml 中的捕蟲囊於共扼焦顯微鏡下做顯像分析，其餘預備做實驗四之實驗。

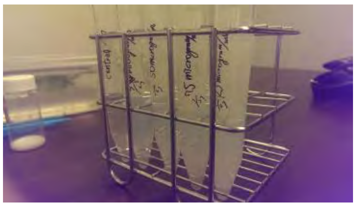
【圖 19】取出植株與放入

(2) 綠色螢光

A. 將步驟一所配製之綠色奈米螢光鑽石溶液取出並稀釋為以下濃度: 125 μg/ml, 100 μg/ml, 75 μg/ml, 50 μg/ml, 25 μg/ml。【圖 20】

B.取出植株並放入溶液中。

C.取所有植株之捕蟲囊於共扼焦顯微鏡下做顯像分析，並將剩餘植株做實驗四之研究。。



【圖 20】溶液與植株

(3) 紅、綠色混合螢光

A. 將綠色奈米鑽石溶液加入紅色奈米鑽石配製成紅、綠色混合螢光溶液。

B.加入植株，放置一月，並觀察其奈米鑽石顯色情形。

4. 植株、奈米鑽石作用與吸附重金屬之量質分析、討論

(1) 導電率差異

A.將實驗三之綠色螢光奈米鑽石植株溶液倒出，並加入 100ppm 硝酸鉛水溶液。【圖 21】

B.靜置 1 天，分別以實驗二之導電率檢測方式測量導電曲線。

【圖 21】溶液倒出示意圖

C. 做完 A 實驗後，將藻體放入水中。
D. 將植株至於共扼焦顯微鏡下，對其做細部差異比較。

5. ND 吸附重金屬研究一(未酸洗之奈米鑽石)

(1) 第一階段

A. 將定量奈米鑽石分為四管。【圖 22】
B. 以水調製飽和溶液後，稀釋硝酸鉛水溶液，分別調配出硝酸鉛濃度 0ppm, 50ppm, 100ppm, 200ppm 之奈米鑽石硝酸鉛水溶液。【圖 23】
C. 放置一天及五天，並運用步驟二之電導度檢驗法測其導電曲線。


【圖 22】定量奈米鑽石分裝


【圖 23】溶液配製

(2) 第二階段(離心後)

A. 將第一階段之試管以離心機 10000 轉/分運作約 20 分鐘。【圖 24】
B. 對離心尚未完全(註 1)之試管再增加離心時間 30 分鐘。
C. 取出上層清澈水溶液，進行步驟二之導電率測試運作 10 分鐘後，再以 Excel 繪表。

註 1:尚未完全即是指該溶液在燈照下仍有光束。
註 2:對試管(無 Pb)由於離心 2 次後仍呈混濁溶液，暫不做下步實驗。


【圖 24】centrifugation

6. ND 吸附重金屬研究二(酸洗後之奈米鑽石 ND-COOH)

(1) 導電率測試

A. 將步驟一配製之奈米鑽石溶液與硝酸鉛、硝酸鎳及硝酸鋅水溶液混合稀釋為奈米鑽石濃度 500~1000 μg/ml 及重金屬離子溶液 50ppm, 100ppm, 200ppm 之混合液體。

B. 配製各種金屬離子及其對應濃度之水溶液，不加奈米鑽石視為對照組。

C. 放置一天半後，取出上層尚為澄清之溶液，並以步驟二之導電率檢測方式測量導電曲線。

(2) 微觀觀察

A. 透過本組所發現的沉澱現象取出沉澱物。

B. 將樣本取出滴於一玻片上，並加熱烘乾。

C. 在圓形平面上塗抹黏膠並將預設之乾樣本黏起，備用，或以刮勺刮下樣本粉末。

D. 將物品置於電子顯微鏡觀察其細部大小、差異與結構。

7. ND 吸附濃度差比較測量(多種)

(1) 一般硝酸金屬溶液配置

A. 將 $Pb(NO_3)_2$、$Ni(NO_3)_2$、$Cu(NO_3)_2$、$Co(NO_3)_2$與 $Fe(NO_3)_3$ 配置成 4000ppm(註 1)備用。

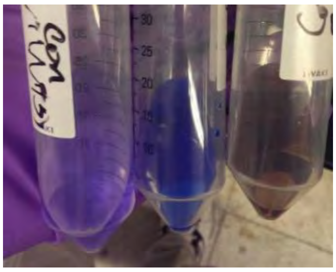
B. 將奈米鑽石水溶液(2mg/ml)加入上述 4000ppm 水溶液

註 1:4000ppm 為本組配置值，由於實驗會有些許誤差，本組亦將原始溶液 ICP 測量，該值則為準確值。

(2) 配置重金屬錯合物

A. 在硝酸鈷加入過量的氨水配置至完全無沉澱為止。

B. 加奈米鑽石以從事吸附效率研究



【圖 25】complex ion

(3) ICP-MS 測量

A. 將樣本離心後備用。

B. 配置標準溶液 (介於 10, 20, 30, 40, 50ppb)。【圖 26】

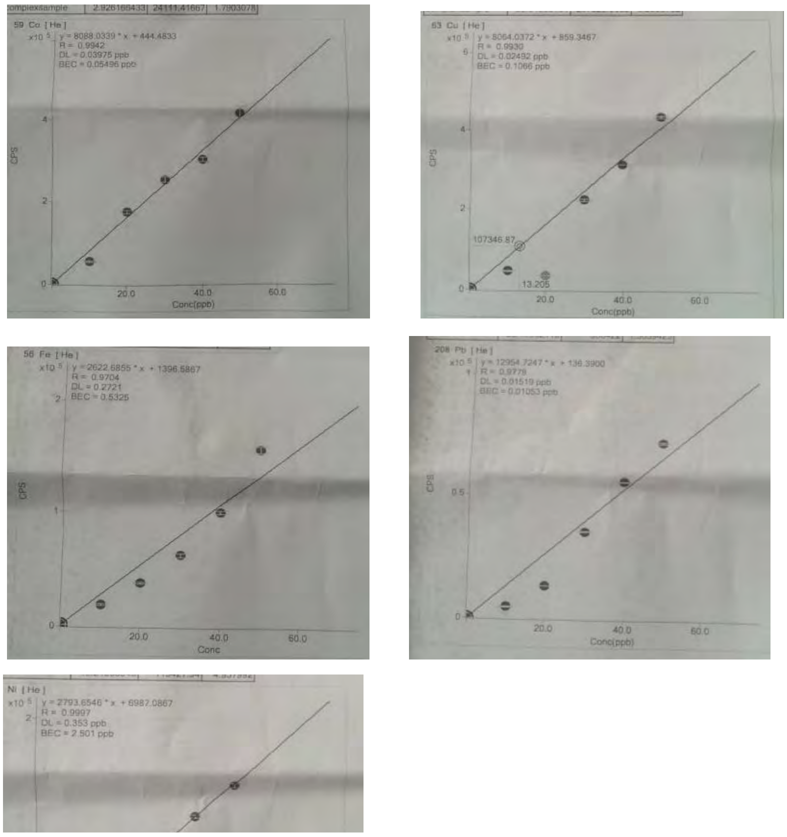
【圖 26】標準溶液配製(10ppb~50ppb)

C. 取出樣本分別將其稀釋至 30ppb 左右(註 1)【圖 27】。

D. 跑 ICP-MS。

【圖 27】樣本稀釋

E. 測定檢量線。



F. 對實驗數據做分析。

註 1:ppb 等級配置原因為 ICP-MS 感應度高，須以較小的濃度防止機器損壞。

三、研究結果與討論

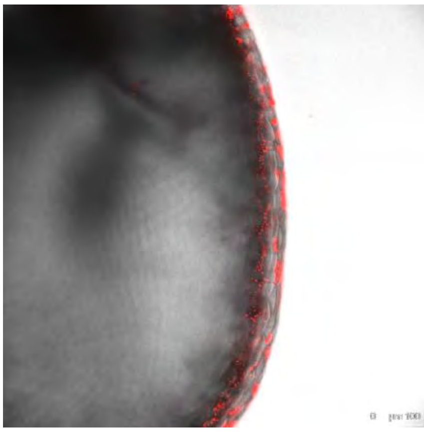
(一) 螢光奈米鑽石對植物之顯像分析

1. 紅色螢光

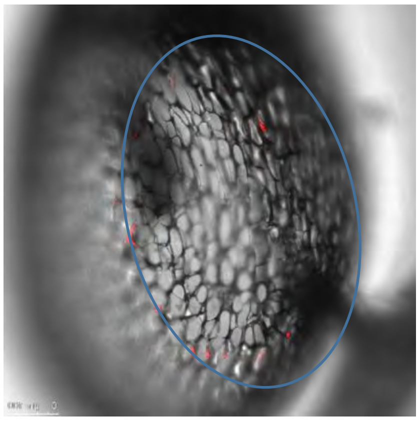
(1). 藻體自體螢光顯像

A. 表皮細胞平面顯像

在共扼焦顯微鏡激發下，可發現本藻體之表皮自體螢光極強，後經一平面掃描可得下【圖 29】，並得之其細胞發光處位於表皮內。【圖 30】則顯示該捕蟲囊上被掃描之區域(藍色線條)有著強烈的自體螢光。



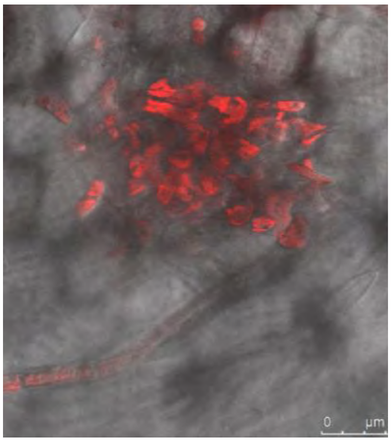
【圖 29】單一平面紅色螢光顯像 1



【圖 30】單一平面紅色螢光顯像 2

B.捕蟲囊內生物體之強烈自體螢光

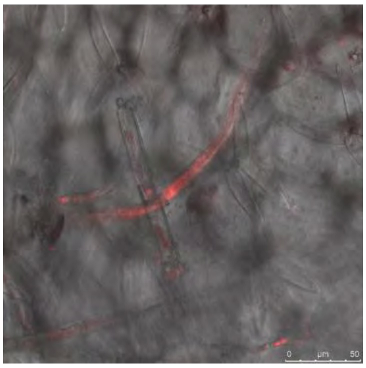
在捕蟲囊內，本組可在電腦上發現其中強烈的紅色螢光團，會移動且有生命跡象，由此可知捕蟲囊為一區域提供其餘生物共生，如【圖 31】所示。



【圖 31】共生生物與其他藻類

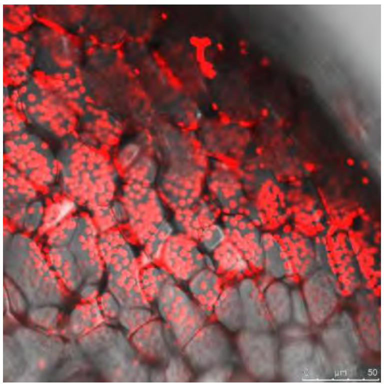
C.捕蟲囊內消化器官~四爪線毛

在【註 3】文獻中提及之四爪線毛在共扼焦顯微鏡顯像下亦可顯影，如【圖 32】所示。


【圖 32】共生藻類與四爪腺毛

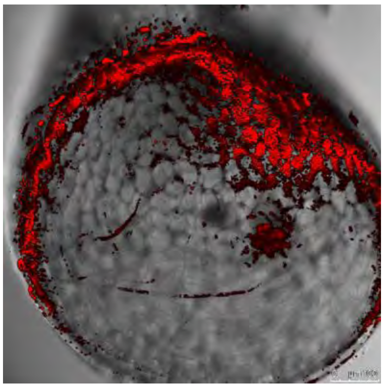
(2). FND red 5 μg/ml 之顯像結果

A. 紅色自體螢光強烈，透過顯微鏡下觀察並無法區別螢光奈米鑽石與自體螢光差別，如【圖 33】所示。

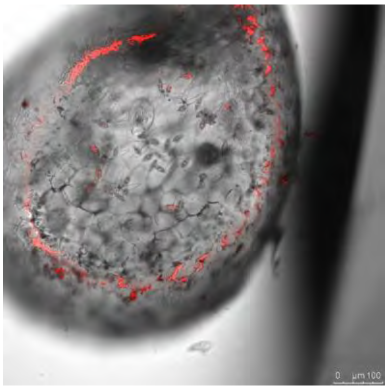

【圖 33】植物表皮平面單層自體螢光

B.表皮細胞單層顯色可看出其表層有不規則形狀，推測可能為奈米鑽石包覆或未成熟之捕蟲囊顯像，如【圖 33】所示。

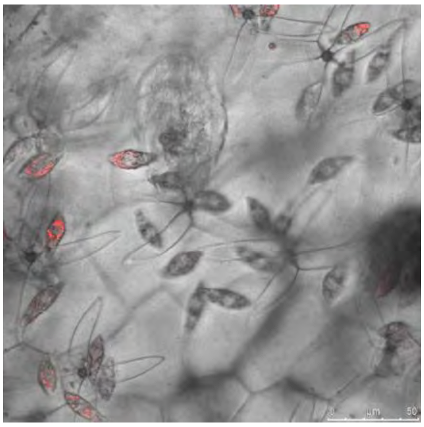
(3). FND red 100 μg/ml 之顯像結果


【圖 34】bladder traps' reflection in 5μg/ml's ND solution.

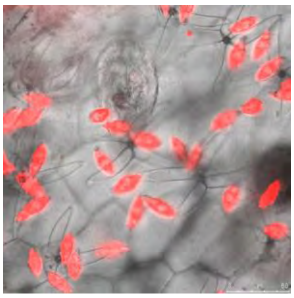
C. 在 FND 100 μg/ml 下之顯像可以反映表層明顯有一層似片狀的覆蓋物，可推測該物即為奈米鑽石，如下【圖 35】所示。


【圖 35】bladder traps' reflection in 100μg/ml's ND solution.

D. 即使有奈米鑽石包覆，亦可發現該囊中生物體仍存活。相對於【圖 31】與【圖 32】，更可發現所有眼蟲有擴散趨勢，下【圖 36】與上【圖 35】明顯可發現其擴散與活動情形。

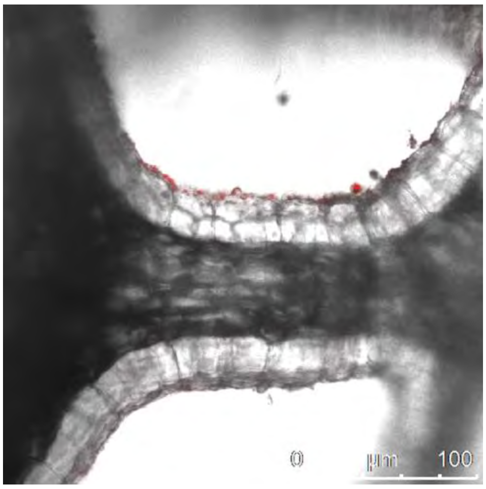

【圖 36】bladder traps' reflection in 100μg/ml's ND solution.

C.【圖 37】是尚未取後段光波之圖，物體與【圖 36】相同，故對照下可發現，所有生物紅色自體螢光都有相當的顯著性。


【圖 37】not gating

(4). FND 吸附特性介紹

就如同動機所述，本組從事重金屬吸附之題目來源，即為本結果所影導，在【圖 1】中可觀察出在莖上的螢光奈米鑽石吸附粒子。



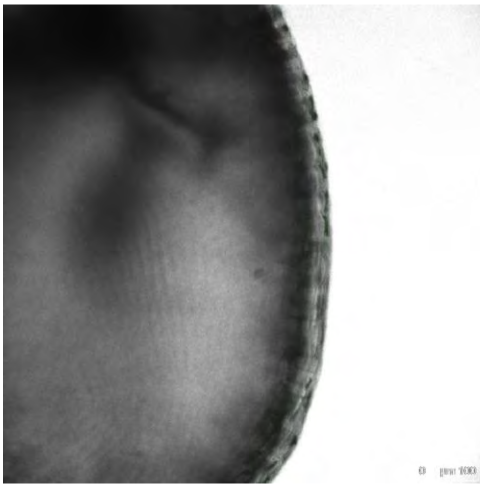
【圖 1】在黃花狸藻上的奈米鑽石沉澱

2.綠色螢光

(1). 藻體自體螢光顯像

A. 表皮自體螢光顯像

在紅色螢光部分明顯了解植物藻體自體螢光之強度，但如【圖 38】所示，其綠色螢光部分並無過強烈之處。


【圖 38】單一切面綠色螢光顯像

(二). 植株、奈米鑽石作用與吸附重金屬之量質分析、討論

1. 不同奈米鑽石吸附下之同量硝酸鉛溶液吸附狀況

(1). 實驗數據

ND 125micro's algae(Pb100ppm) — 2 days 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance	25.180	24.687	24.206	24.192	23.733	23.276	22.841	22.414	20.887	19.566	19.256	18.948	18.651	18.364	17.830	17.558	17.314	17.303	17.300	17.05
nductivity for 100ppm Lead nitrate ND 125 mic	0.040	0.041	0.041	0.041	0.042	0.043	0.044	0.045	0.048	0.051	0.052	0.053	0.054	0.054	0.056	0.057	0.058	0.058	0.058	0.059
V	12.842	12.837	12.829	12.822	12.816	12.802	12.791	12.776	12.741	12.718	12.709	12.695	12.683	12.671	12.659	12.642	12.639	12.631	12.629	12.61
I	0.510	0.520	0.530	0.53	0.540	0.550	0.560	0.57	0.61	0.65	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.73	0.73	0.7

ND 75micro's algae(Pb) — 2 days 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance	48.474	46.725	46.718	45.066	43.550	43.533	43.517	46.693	46.700	46.696	46.675	45.045	43.523	42.100	39.524	40.753	39.506	39.482	38.297	37.18
onductivity for 100ppm Lead nitrate ND 75 mic	0.021	0.021	0.021	0.022	0.023	0.023	0.023	0.021	0.021	0.021	0.021	0.022	0.023	0.024	0.025	0.025	0.025	0.025	0.026	0.027
V	13.088	13.083	13.081	13.069	13.065	13.060	13.055	13.074	13.076	13.075	13.069	13.063	13.057	13.051	13.043	13.041	13.037	13.029	13.021	13.01
I	0.270	0.280	0.280	0.29	0.300	0.300	0.300	0.28	0.28	0.28	0.28	0.29	0.3	0.31	0.33	0.32	0.33	0.33	0.34	0.3

ND 50micro's algae(Pb) — 2 days 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance	26.856	26.854	26.844	26.829	26.247	25.716	25.200	24.698	24.221	24.206	23.743	23.280	22.433	22.024	21.642	20.897	20.547	20.210	20.195	19.86
onductivity for 100ppm Lead nitrate ND 50micr	0.037	0.037	0.037	0.037	0.038	0.039	0.040	0.040	0.041	0.041	0.042	0.043	0.045	0.045	0.046	0.048	0.049	0.049	0.050	0.050
V	12.891	12.890	12.885	12.878	12.861	12.858	12.852	12.843	12.837	12.829	12.821	12.804	12.787	12.774	12.769	12.747	12.739	12.732	12.723	12.71
I	0.480	0.480	0.480	0.48	0.490	0.500	0.510	0.52	0.53	0.53	0.54	0.55	0.57	0.58	0.59	0.61	0.62	0.63	0.63	0.6

ND 25micro's algae(Pb) — 2 days 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance	39.488	38.309	38.288	36.139	36.128	36.106	36.100	35.116	35.103	34.168	33.274	33.241	31.600	31.595	31.590	31.580	30.819	31.578	30.821	30.81
onductivity for 100ppm Lead nitrate ND 25micr	0.025	0.026	0.026	0.028	0.028	0.028	0.028	0.028	0.028	0.029	0.030	0.030	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
V	13.031	13.025	13.018	13.01	13.006	12.998	12.996	12.993	12.988	12.984	12.977	12.964	12.956	12.954	12.952	12.948	12.944	12.947	12.945	12.94
I	0.330	0.340	0.340	0.36	0.360	0.360	0.360	0.37	0.37	0.38	0.39	0.39	0.41	0.41	0.41	0.41	0.42	0.41	0.42	0.4

no ND algae(Pb) — 2 days 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance	39.506	39.488	38.306	36.144	36.128	36.119	34.200	34.168	33.256	33.262	31.605	32.415	32.405	31.600	30.836	31.590	30.836	30.831	31.580	30.83
conductivity for 100ppm Lead nitrate control	0.025	0.025	0.026	0.028	0.028	0.028	0.029	0.029	0.030	0.030	0.032	0.031	0.031	0.032	0.032	0.032	0.032	0.032	0.032	0.032
V	13.037	13.031	13.024	13.012	13.006	13.003	12.996	12.984	12.97	12.972	12.958	12.966	12.962	12.956	12.951	12.952	12.951	12.949	12.948	12.94
I	0.330	0.330	0.340	0.36	0.360	0.360	0.380	0.38	0.39	0.39	0.41	0.4	0.4	0.41	0.42	0.41	0.42	0.42	0.41	0.4

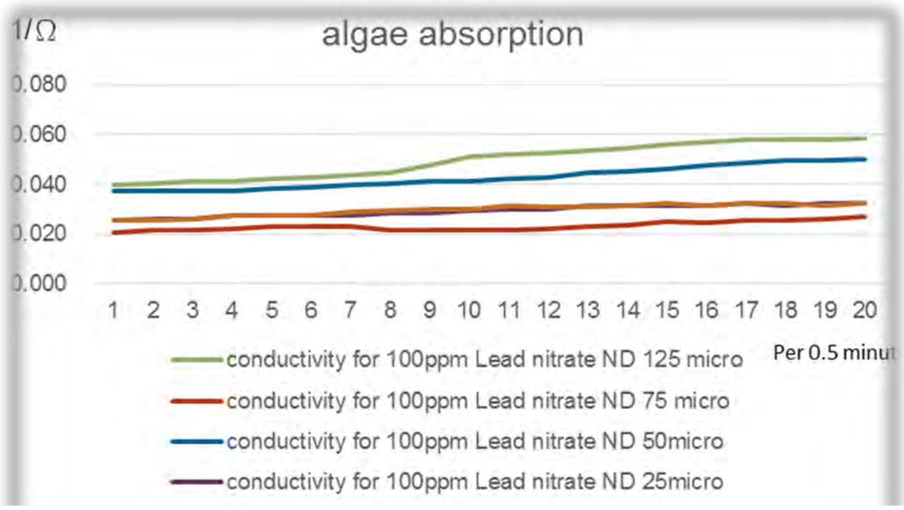
Lead 1 100ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
resistance for 100ppm Lead nitrate	8.922	9.066	9.072	9.220	9.389	9.461	9.384	9.386	9.310	9.235	9.303	9.302	9.298	9.145	9.208	9.058	8.986	8.922	8.919	8.77
conductivity for 100ppm Lead nitrate	0.112	0.110	0.110	0.108	0.107	0.106	0.107	0.107	0.107	0.108	0.107	0.108	0.108	0.109	0.109	0.110	0.111	0.112	0.112	0.114
V	11.955	11.967	11.975	11.986	12.018	12.016	12.011	12.014	12.01	12.005	12.001	12	11.995	11.98	11.971	11.956	11.952	11.956	11.952	11.93
I	1.340	1.320	1.320	1.3	1.280	1.270	1.280	1.28	1.29	1.3	1.29	1.29	1.29	1.31	1.3	1.32	1.33	1.34	1.34	1.3

【表 1】不同濃度數據顯示結果(Voltage/Current=resistance, 1/resistance=conductivity)

(2). 實驗圖表

【表 2】不同濃度數據顯示圖表



2.現象概述

a. 從【表 1】與【表 2】中，本組可以強調其必有吸附重金屬梨子的功效。所有含植物的溶液中，暫不論其上 FND 含量，皆具有吸附功能，透過導電度，本組可清楚了解吸附的重要指標。

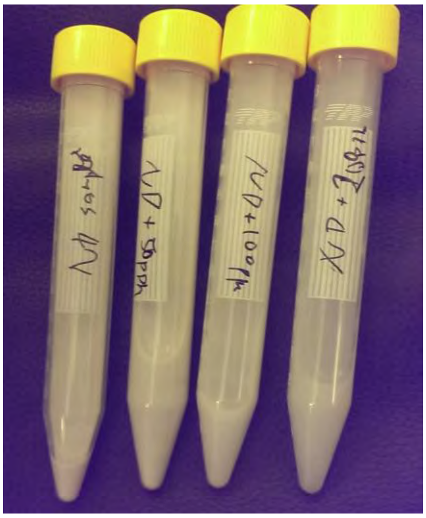
b. 對於不同濃度溶液下所產生的吸附，並無法發掘其明顯的規律性，故此實驗無法指出不同 ND 對吸附關係的影響。

(三) ND(尚未酸洗)與重金屬之共同放置反應(離心前)

1.外觀差異

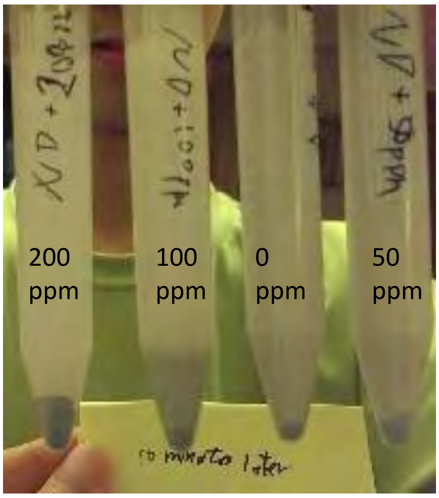
(1) 0 minutes: 放入奈米鑽石初期，並不會有明顯差異。

【圖 39】放入 ND (0 minutes) 白底



【圖 40】放入 ND (0 minutes) 黑底

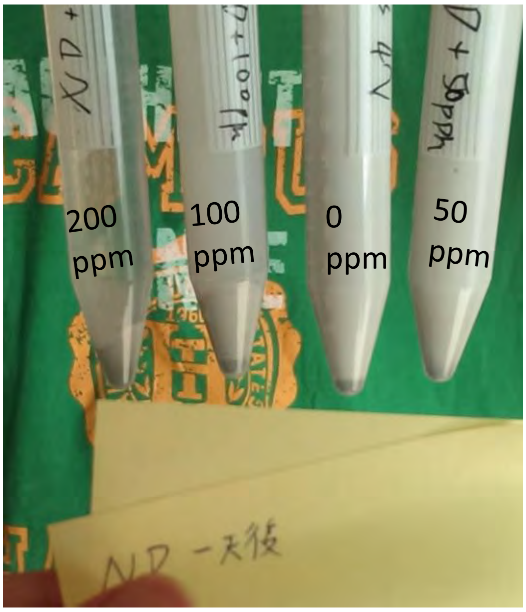
(2). 10 minutes: 放入奈米鑽石十分鐘後，不同硝酸鉛濃度的溶液開始可以觀察到差異，200ppm 之硝酸鉛溶液含最深之身色沉澱，其餘溶液隨硝酸鉛濃度減少，黑色沉澱範圍逐漸縮小。上述如【圖 41】所示。



【圖 41】放入 ND (10 minutes)

(3) 1 day

放置一天後，硝酸鉛濃度為 200ppm 之奈米鑽石溶液較【圖 41】之溶液而言，上方液體清澈度明顯提高，下方沉澱物也有些許增加。至於 100ppm，本組也可發現下方黑色沉澱物有增加趨勢，上述如【圖 42】所示

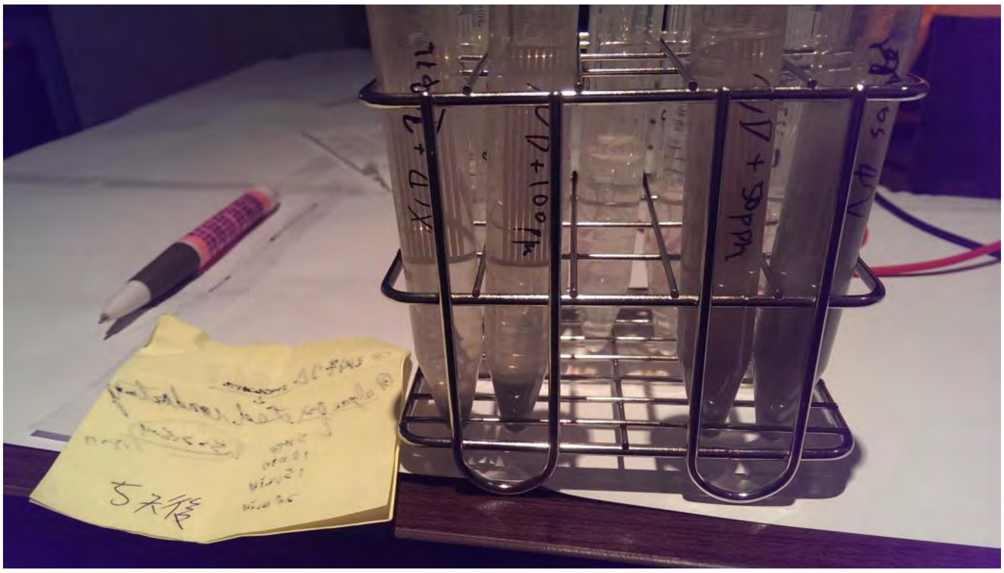


【圖 42】放入 ND (1 day)

(13)

(4) 5days

放置五天後，可迅速分別出各濃度的差異，並可再次證明濃度與沉澱量關係。隨著時間增加，亦可發現硝酸鉛溶液 100ppm 的清澈度上升，此現象可證明時間與沉澱量或清澈度之連結，如【圖 43】所示。



【圖 43】放入 ND (5 days)

(5) 現象概述

A. 時間增加可增加溶液清澈度與沉澱量

B. 重金屬濃度越高，溶液上方液體越容易清澈。

C. 此現象可能來自重金屬與奈米鑽石的結合變重所致，須看微觀來證明。

D. 因此批樣本只將其配製飽和某些沉澱現象是原本的奈米鑽石，故用清澈度檢測較為精準。

2.導電率變化

(1) 圖表與數據文字敘述

由【表 5】可得知放入奈米鑽石的確具減少導電度作用，但見【表 6】、【表 9】和【表 12】時，導電率卻有不減反增的現象。見【表 10】及此份奈米鑽石的特質可得知，因其為未酸洗之批，故上面連接的官能基尚無法確定，或能提及裡面之物體繁複。雖因無法確定之樣本來做此實驗並不能從導電度確定其是否有吸收重金屬之效，但能提出一假設:裡面的組成成分正在改變甚有大幅改變的趨勢，若透過先前所提及的沉澱現象亦可證明導電度的假設是正確無誤的。

(2) 不同濃度下之分別比較

透過不同濃度下所記錄的圖表與數據觀察不同導電率下的

影響與差異。

I. 200 ppm

Lead 200ppm

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance for 200ppm Lead nitrate	8.184	8.065	8.000	7.999	7.940	7.883	7.881	7.881	7.820	7.544
conductivity for 200ppm Lead nitrate	0.122	0.124	0.125	0.125	0.126	0.127	0.127	0.127	0.128	0.133
13.3-V for 200ppm Lead nitrate	1.433	1.445	1.460	1.462	1.470	1.476	1.479	1.478	1.492	1.531
V	11.867	11.855	11.840	11.838	11.830	11.824	11.821	11.822	11.808	11.769
I	1.450	1.470	1.480	1.48	1.490	1.500	1.500	1.5	1.51	1.56
LED	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
7.430	7.420	7.210	6.933	6.881	6.878	6.785	6.744	7.027	6.930	6.832	6.565	6.439	6.352	6.228	6.082	5.725	5.650	5.560	5.562
0.135	0.135	0.139	0.144	0.145	0.145	0.147	0.148	0.142	0.144	0.146	0.152	0.155	0.157	0.161	0.164	0.175	0.177	0.180	0.180
1.561	1.576	1.619	1.653	1.671	1.676	1.697	1.701	1.636	1.657	1.686	1.745	1.775	1.803	1.840	1.865	1.965	2.000	2.014	2.009
11.739	11.724	11.681	11.647	11.629	11.624	11.603	11.599	11.664	11.643	11.614	11.555	11.525	11.497	11.46	11.435	11.335	11.3	11.286	11.291
1.58	1.58	1.62	1.68	1.69	1.69	1.71	1.72	1.66	1.68	1.7	1.76	1.79	1.81	1.84	1.88	1.98	2	2.03	2.03
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
5.558	5.493	5.369	5.334	5.338	5.372	5.529	5.494	5.492	5.397	5.341	5.364	5.520	5.308	5.251	4.996	4.863	4.713	4.639	4.611
0.180	0.182	0.186	0.187	0.187	0.186	0.181	0.182	0.182	0.185	0.187	0.186	0.181	0.188	0.190	0.200	0.206	0.212	0.216	0.217
2.018	2.039	2.079	2.098	2.091	2.073	2.020	2.038	2.042	2.074	2.084	2.089	2.040	2.101	2.115	2.209	2.262	2.319	2.351	2.372
11.282	11.261	11.221	11.202	11.209	11.227	11.28	11.262	11.258	11.226	11.216	11.211	11.26	11.199	11.185	11.091	11.038	10.981	10.949	10.928
2.03	2.05	2.09	2.1	2.1	2.09	2.04	2.05	2.05	2.08	2.1	2.09	2.04	2.11	2.13	2.22	2.27	2.33	2.36	2.37
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
4.609	4.633	4.495	4.517	4.539	4.529	4.492	4.427	4.422	4.356
0.217	0.216	0.222	0.221	0.220	0.221	0.223	0.226	0.226	0.230
2.377	2.366	2.423	2.413	2.406	2.386	2.429	2.454	2.466	2.497
10.923	10.934	10.877	10.887	10.894	10.914	10.871	10.846	10.834	10.803
2.37	2.36	2.42	2.41	2.4	2.41	2.42	2.45	2.45	2.48
3	3	3	3	3	3	3	3	3	3

【表 3】Lead 200ppm 數據

ND only - 200ppm Lead nitrate 1day precipitates

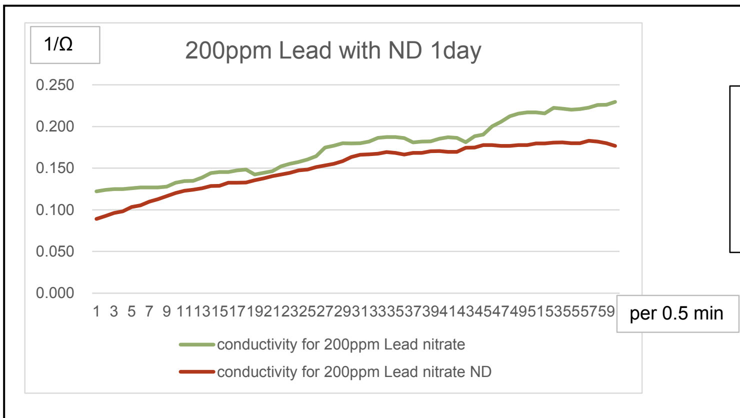
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	11.225	10.791	10.391	10.191	9.660	9.490	9.099	8.873	8.588	8.320
conductivity for 200ppm Lead nitrate ND	0.089	0.093	0.096	0.098	0.104	0.105	0.110	0.113	0.116	0.120
13.3-V for 200ppm Lead nitrate ND	1.065	1.106	1.143	1.173	1.225	1.248	1.289	1.321	1.363	1.402
V	12.235	12.194	12.157	12.127	12.075	12.052	12.011	11.979	11.937	11.898
I	1.09	1.13	1.17	1.19	1.25	1.27	1.32	1.35	1.39	1.43
LED	1	1	1	1	1	1	1	1	1	1

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
8.132	8.057	7.944	7.769	7.765	7.548	7.540	7.535	7.375	7.265	7.120	7.024	6.925	6.789	6.742	6.608	6.525	6.441	6.315	6.124
0.123	0.124	0.126	0.129	0.129	0.132	0.133	0.133	0.136	0.138	0.140	0.142	0.144	0.147	0.148	0.151	0.153	0.155	0.158	0.163
1.427	1.456	1.463	1.491	1.497	1.525	1.537	1.546	1.574	1.604	1.623	1.640	1.666	1.691	1.704	1.736	1.751	1.770	1.807	1.849
11.873	11.844	11.837	11.809	11.803	11.775	11.763	11.754	11.726	11.696	11.677	11.66	11.634	11.609	11.596	11.564	11.549	11.53	11.493	11.451
1.46	1.47	1.49	1.52	1.52	1.56	1.56	1.56	1.59	1.61	1.64	1.66	1.68	1.71	1.72	1.75	1.77	1.79	1.82	1.87
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
6.016	6.006	5.973	5.905	5.936	6.008	5.941	5.937	5.871	5.865	5.898	5.901	5.727	5.725	5.627	5.624	5.656	5.662	5.628	5.624
0.166	0.167	0.167	0.169	0.168	0.166	0.168	0.168	0.170	0.170	0.170	0.169	0.175	0.175	0.178	0.178	0.177	0.177	0.178	0.178
1.869	1.889	1.892	1.903	1.902	1.884	1.894	1.901	1.911	1.921	1.917	1.911	1.960	1.964	1.990	1.995	1.988	1.977	1.987	1.995
11.431	11.411	11.408	11.397	11.398	11.416	11.406	11.399	11.389	11.379	11.383	11.389	11.34	11.336	11.31	11.305	11.312	11.323	11.313	11.305
1.90	1.90	1.91	1.93	1.92	1.90	1.92	1.92	1.94	1.94	1.93	1.93	1.98	1.98	2.01	2.01	2.00	2.00	2.01	2.01
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
5.562	5.563	5.532	5.526	5.558	5.559	5.466	5.496	5.558	5.661
0.180	0.180	0.181	0.181	0.180	0.180	0.183	0.182	0.180	0.177
2.009	2.008	2.015	2.026	2.018	2.015	2.041	2.034	2.018	1.978
11.291	11.292	11.285	11.274	11.282	11.285	11.259	11.266	11.282	11.322
2.03	2.03	2.04	2.04	2.03	2.03	2.06	2.05	2.03	2.00
2	2	2	2	2	2	2	2	2	2

【表 4】Lead 200ppm 進 ND(未酸洗)數



【表 5】200ppm Lead ND and No ND’s comparison

II. 100ppm

100ppm Lead nitrate twice

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	18.597	18.585	18.578	18.300	18.034	18.029	17.251	16.997	16.769	17.003
conductivity for 100ppm Lead nitrate	0.054	0.054	0.054	0.055	0.055	0.055	0.058	0.059	0.060	0.059
13.3-V for 100ppm Lead nitrate	0.654	0.662	0.667	0.673	0.676	0.680	0.707	0.722	0.723	0.718
V	12.646	12.638	12.633	12.627	12.624	12.620	12.593	12.578	12.577	12.582
I	0.68	0.68	0.68	0.69	0.70	0.70	0.73	0.74	0.75	0.74

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
16.997	16.532	16.529	16.534	16.086	16.077	16.765	16.537	16.077	15.447	15.447	15.054	15.039	14.849	14.667	14.148	13.808	13.635	13.627	13.470
0.059	0.060	0.060	0.060	0.062	0.062	0.060	0.060	0.062	0.065	0.065	0.066	0.066	0.067	0.068	0.071	0.072	0.073	0.073	0.074
0.722	0.736	0.738	0.734	0.753	0.760	0.726	0.732	0.760	0.788	0.788	0.805	0.818	0.827	0.833	0.850	0.873	0.892	0.899	0.908
12.578	12.564	12.562	12.566	12.547	12.54	12.574	12.568	12.54	12.512	12.512	12.495	12.482	12.473	12.467	12.45	12.427	12.408	12.401	12.392
0.74	0.76	0.76	0.76	0.78	0.78	0.75	0.76	0.78	0.81	0.81	0.83	0.83	0.84	0.85	0.88	0.90	0.91	0.91	0.92

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
13.025	12.593	12.587	12.188	12.187	12.188	11.941	11.693	11.453	11.453	11.569	11.343	11.445	11.338	11.560	11.454	11.330	11.330	11.332	11.559
0.077	0.079	0.079	0.082	0.082	0.082	0.084	0.086	0.087	0.087	0.086	0.088	0.087	0.088	0.087	0.087	0.088	0.088	0.088	0.087
0.926	0.959	0.965	0.990	0.991	0.990	1.001	1.022	1.045	1.045	1.037	1.050	1.054	1.055	1.046	1.044	1.064	1.064	1.061	1.047
12.374	12.341	12.335	12.31	12.309	12.31	12.299	12.278	12.255	12.255	12.263	12.25	12.246	12.245	12.254	12.256	12.236	12.236	12.239	12.253
0.95	0.98	0.98	1.01	1.01	1.01	1.03	1.05	1.07	1.07	1.06	1.08	1.07	1.08	1.06	1.07	1.08	1.08	1.08	1.06

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
11.805	11.804	11.797	11.930	12.180	12.061	12.310	12.452	12.325	12.576
0.085	0.085	0.085	0.084	0.082	0.083	0.081	0.080	0.081	0.080
1.023	1.024	1.031	1.012	0.998	0.998	0.990	0.973	0.975	0.976
12.277	12.276	12.269	12.288	12.302	12.302	12.31	12.327	12.325	12.324
1.04	1.04	1.04	1.03	1.01	1.02	1.00	0.99	1.00	0.98

【表 6】Lead 100ppm 數據

ND only - 100ppm Lead nitrate 1day suspension

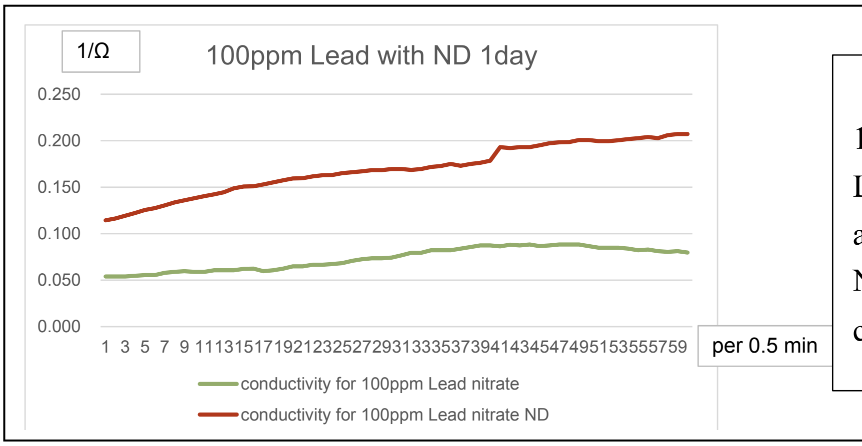
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	8.759	8.602	8.383	8.175	7.975	7.842	7.665	7.485	7.363	7.248
conductivity for 100ppm Lead nitrate ND	0.114	0.116	0.119	0.122	0.125	0.128	0.130	0.134	0.136	0.138
13.3-V for 100ppm Lead nitrate ND	2.264	2.289	2.318	2.346	2.374	2.400	2.416	2.447	2.476	2.500
V	11.036	11.011	10.982	10.954	10.926	10.900	10.884	10.853	10.824	10.8
I	1.260	1.280	1.310	1.34	1.370	1.390	1.420	1.45	1.47	1.49
LED	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
7.134	7.027	6.923	6.730	6.639	6.627	6.536	6.444	6.359	6.275	6.267	6.188	6.145	6.137	6.059	6.021	5.984	5.947	5.944	5.901
0.140	0.142	0.144	0.149	0.151	0.151	0.153	0.155	0.157	0.159	0.160	0.162	0.163	0.163	0.165	0.166	0.167	0.168	0.168	0.169
2.527	2.549	2.569	2.599	2.612	2.631	2.647	2.668	2.680	2.696	2.709	2.719	2.731	2.745	2.757	2.763	2.768	2.774	2.780	2.796
10.773	10.751	10.731	10.701	10.688	10.669	10.653	10.632	10.62	10.604	10.591	10.581	10.569	10.555	10.543	10.537	10.532	10.526	10.52	10.504
1.51	1.53	1.55	1.59	1.61	1.61	1.63	1.65	1.67	1.69	1.69	1.71	1.72	1.72	1.74	1.75	1.76	1.77	1.77	1.78
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
5.903	5.938	5.899	5.823	5.787	5.719	5.782	5.713	5.674	5.606	5.183	5.208	5.183	5.182	5.126	5.071	5.043	5.039	4.984	4.982
0.169	0.168	0.170	0.172	0.173	0.175	0.173	0.175	0.176	0.178	0.193	0.192	0.193	0.193	0.195	0.197	0.198	0.198	0.201	0.201
2.793	2.790	2.799	2.818	2.826	2.834	2.834	2.846	2.860	2.872	2.157	2.155	2.156	2.158	2.176	2.194	2.206	2.214	2.235	2.240
10.507	10.51	10.501	10.482	10.474	10.466	10.466	10.454	10.44	10.428	11.143	11.145	11.144	11.142	11.124	11.106	11.094	11.086	11.065	11.06
1.78	1.77	1.78	1.8	1.81	1.83	1.81	1.83	1.84	1.86	2.15	2.14	2.15	2.15	2.17	2.19	2.2	2.2	2.22	2.22
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
5.013	5.015	4.986	4.957	4.931	4.906	4.932	4.856	4.828	4.828
0.199	0.199	0.201	0.202	0.203	0.204	0.203	0.206	0.207	0.207
2.222	2.217	2.230	2.247	2.254	2.262	2.253	2.277	2.292	2.293
11.078	11.083	11.07	11.053	11.046	11.038	11.047	11.023	11.008	11.007
2.21	2.21	2.22	2.23	2.24	2.25	2.24	2.27	2.28	2.28
2	2	2	2	2	2	2	2	2	2

【表 7】Lead 100ppm 進 ND(未酸洗)數據



【表 8】100ppm Lead ND and No ND’ s comparison

III. 50 ppm

50ppm Lead nitrate

details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	24.206	24.685	25.173	25.706	25.190	24.681	24.189	23.731	23.282	22.846
conductivity for 50ppm Lead nitrate	0.041	0.041	0.040	0.039	0.040	0.041	0.041	0.042	0.043	0.044
13.3-V for 50ppm Lead nitrate	0.471	0.464	0.462	0.447	0.453	0.466	0.480	0.485	0.495	0.506
V	12.829	12.836	12.838	12.853	12.847	12.834	12.820	12.815	12.805	12.794
I	0.53	0.52	0.51	0.50	0.51	0.52	0.53	0.54	0.55	0.56

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
22.423	22.028	21.632	20.898	20.897	21.255	21.634	21.258	20.189	19.538	18.940	19.864	19.866	19.859	18.635	18.343	18.641	19.532	19.545	19.529
0.045	0.045	0.046	0.048	0.048	0.047	0.046	0.047	0.050	0.051	0.053	0.050	0.050	0.050	0.054	0.055	0.054	0.051	0.051	0.051
0.519	0.524	0.537	0.552	0.553	0.547	0.536	0.545	0.581	0.600	0.610	0.587	0.586	0.590	0.628	0.643	0.624	0.604	0.596	0.606
12.781	12.776	12.763	12.748	12.747	12.753	12.764	12.755	12.719	12.7	12.69	12.713	12.714	12.71	12.672	12.657	12.676	12.696	12.704	12.694
0.57	0.58	0.59	0.61	0.61	0.60	0.59	0.60	0.63	0.65	0.67	0.64	0.64	0.64	0.68	0.69	0.68	0.65	0.65	0.65

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
19.224	19.230	19.235	19.548	20.197	19.873	19.239	19.238	19.546	20.877	20.874	19.867	19.551	19.552	20.529	20.195	20.195	19.560	19.239	19.560
0.052	0.052	0.052	0.051	0.050	0.050	0.052	0.052	0.051	0.048	0.048	0.050	0.051	0.051	0.049	0.050	0.050	0.051	0.052	0.051
0.612	0.608	0.605	0.594	0.576	0.581	0.602	0.603	0.595	0.565	0.567	0.585	0.592	0.591	0.572	0.577	0.577	0.586	0.602	0.586
12.688	12.692	12.695	12.706	12.724	12.719	12.698	12.697	12.705	12.735	12.733	12.715	12.708	12.709	12.728	12.723	12.723	12.714	12.698	12.714
0.66	0.66	0.66	0.65	0.63	0.64	0.66	0.66	0.65	0.61	0.61	0.64	0.65	0.65	0.62	0.63	0.63	0.65	0.66	0.65

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
20.885	22.026	22.019	21.245	20.552	20.544	20.907	20.561	20.539	20.537
0.048	0.045	0.045	0.047	0.049	0.049	0.048	0.049	0.049	0.049
0.560	0.525	0.529	0.553	0.558	0.563	0.547	0.552	0.566	0.567
12.74	12.775	12.771	12.747	12.742	12.737	12.753	12.748	12.734	12.733
0.61	0.58	0.58	0.60	0.62	0.62	0.61	0.62	0.62	0.62

【表 9】Lead 50ppm 數據

ND only - 50ppm Lead nitrate 1 day

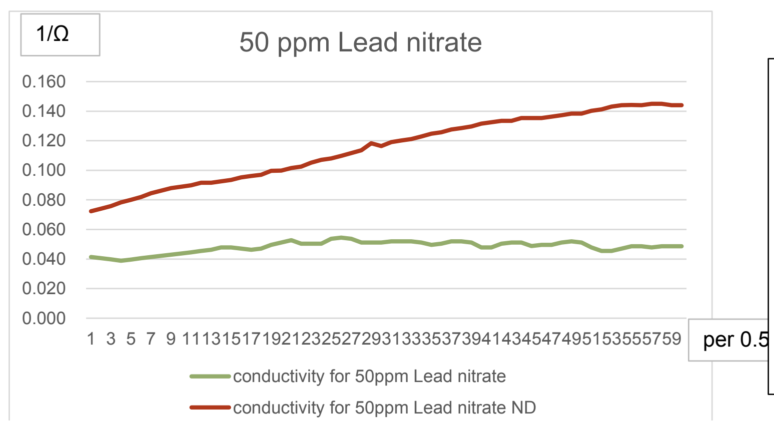
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	13.823	13.502	13.188	12.756	12.478	12.209	11.835	11.591	11.362	11.245
conductivity for 50ppm Lead nitrate ND	0.072	0.074	0.076	0.078	0.080	0.082	0.084	0.086	0.088	0.089
V	12.441	12.422	12.397	12.373	12.353	12.331	12.308	12.286	12.271	12.257
I	0.900	0.920	0.940	0.97	0.990	1.010	1.040	1.06	1.08	1.09
13.3-V for 50ppm Lead nitrate ND	0.859	0.878	0.903	0.927	0.947	0.969	0.992	1.014	1.029	1.043

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
11.128	10.914	10.912	10.804	10.698	10.506	10.402	10.304	10.036	10.023	9.840	9.751	9.504	9.344	9.258	9.105	8.955	8.811	8.449	8.594
0.090	0.092	0.092	0.093	0.093	0.095	0.096	0.097	0.100	0.100	0.102	0.103	0.105	0.107	0.108	0.110	0.112	0.113	0.118	0.116
12.241	12.224	12.221	12.209	12.196	12.187	12.17	12.159	12.143	12.128	12.103	12.091	12.07	12.054	12.036	12.019	12	11.983	11.66	11.946
1.1	1.12	1.12	1.13	1.14	1.16	1.17	1.18	1.21	1.21	1.23	1.24	1.27	1.29	1.3	1.32	1.34	1.36	1.38	1.39
1.059	1.076	1.079	1.091	1.104	1.113	1.130	1.141	1.157	1.172	1.197	1.209	1.230	1.246	1.264	1.281	1.300	1.317	1.640	1.354

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
8.397	8.324	8.259	8.137	8.018	7.952	7.836	7.775	7.713	7.605	7.546	7.495	7.490	7.386	7.387	7.385	7.336	7.285	7.228	7.227
0.119	0.120	0.121	0.123	0.125	0.126	0.128	0.129	0.130	0.132	0.133	0.133	0.134	0.135	0.135	0.135	0.136	0.137	0.138	0.138
11.924	11.904	11.893	11.88	11.866	11.849	11.832	11.818	11.801	11.787	11.772	11.767	11.76	11.743	11.745	11.742	11.738	11.729	11.71	11.708
1.42	1.43	1.44	1.46	1.48	1.49	1.51	1.52	1.53	1.55	1.56	1.57	1.57	1.59	1.59	1.59	1.6	1.61	1.62	1.62
1.376	1.396	1.407	1.420	1.434	1.451	1.468	1.482	1.499	1.513	1.528	1.533	1.540	1.557	1.555	1.558	1.562	1.571	1.590	1.592

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
7.127	7.078	6.987	6.939	6.937	6.939	6.895	6.895	6.938	6.939
0.140	0.141	0.143	0.144	0.144	0.144	0.145	0.145	0.144	0.144
11.689	11.679	11.668	11.657	11.654	11.657	11.653	11.653	11.656	11.657
1.64	1.65	1.67	1.68	1.68	1.68	1.69	1.69	1.68	1.68
1.611	1.621	1.632	1.643	1.646	1.643	1.647	1.647	1.644	1.643

【表 10】Lead 50ppm 進 ND(未酸洗)數據



【表 11】50ppm Lead ND and No ND’s comparison

IV. Control

ND only - control

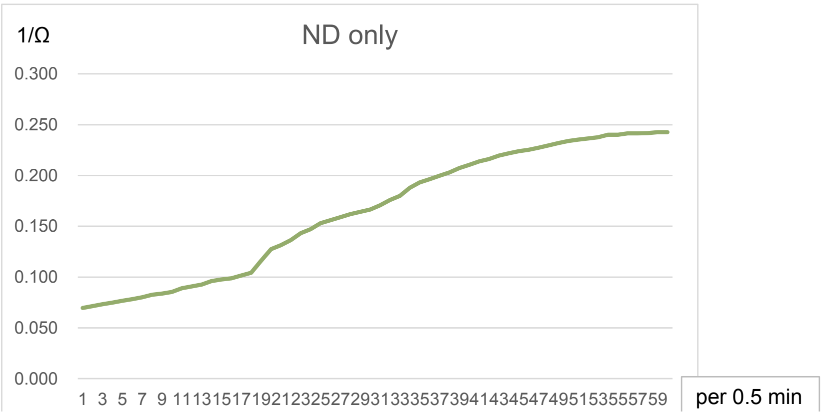
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	14.345	14.004	13.668	13.357	13.049	12.759	12.478	12.088	11.951	11.701
ND only	0.070	0.071	0.073	0.075	0.077	0.078	0.080	0.083	0.084	0.085
V	12.480	12.464	12.438	12.422	12.397	12.376	12.353	12.33	12.31	12.286
I	0.870	0.890	0.910	0.93	0.950	0.970	0.990	1.02	1.03	1.05
13.3-V for control (NO METAL) ND	0.820	0.836	0.862	0.878	0.903	0.924	0.947	0.970	0.990	1.014

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
11.244	11.020	10.805	10.419	10.229	10.120	9.853	9.592	8.618	7.840	7.605	7.333	6.985	6.799	6.537	6.413	6.290	6.173	6.092	6.006
0.089	0.091	0.093	0.096	0.098	0.099	0.101	0.104	0.116	0.128	0.131	0.136	0.143	0.147	0.153	0.156	0.159	0.162	0.164	0.166
12.256	12.232	12.21	12.19	12.172	12.144	12.119	12.086	11.204	11.839	11.788	11.732	11.665	11.626	11.57	11.543	11.51	11.482	11.453	11.412
1.09	1.11	1.13	1.17	1.19	1.2	1.23	1.26	1.3	1.51	1.55	1.6	1.67	1.71	1.77	1.8	1.83	1.86	1.88	1.9
1.044	1.068	1.090	1.110	1.128	1.156	1.181	1.214	2.096	1.461	1.512	1.568	1.635	1.674	1.730	1.757	1.790	1.818	1.847	1.888

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
5.864	5.684	5.558	5.321	5.177	5.091	5.006	4.924	4.826	4.750	4.675	4.624	4.555	4.509	4.463	4.438	4.397	4.356	4.313	4.272
0.171	0.176	0.180	0.188	0.193	0.196	0.200	0.203	0.207	0.211	0.214	0.216	0.220	0.222	0.224	0.225	0.227	0.230	0.232	0.234
11.376	11.312	11.283	11.227	11.182	11.149	11.114	11.079	11.051	11.019	10.986	10.958	10.931	10.911	10.89	10.872	10.86	10.846	10.825	10.809
1.94	1.99	2.03	2.11	2.16	2.19	2.22	2.25	2.29	2.32	2.35	2.37	2.4	2.42	2.44	2.45	2.47	2.49	2.51	2.53
1.924	1.988	2.017	2.073	2.118	2.151	2.186	2.221	2.249	2.281	2.314	2.342	2.369	2.389	2.410	2.428	2.440	2.454	2.475	2.491

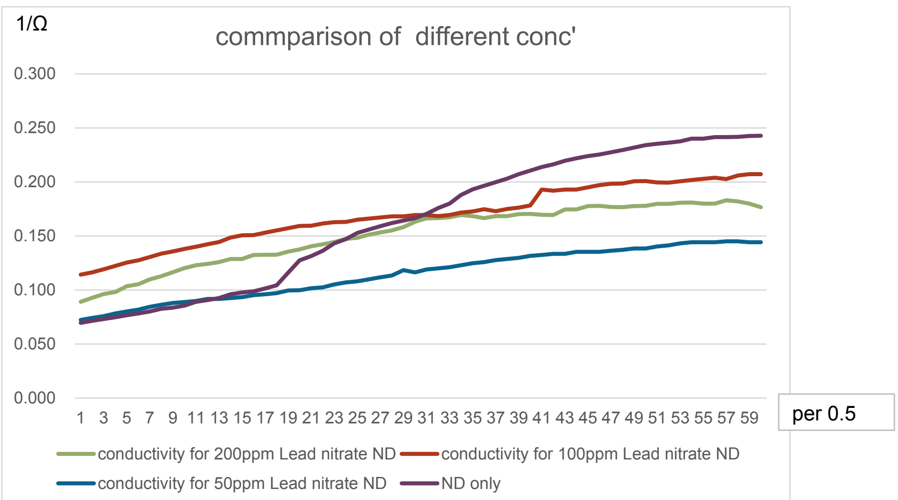
25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
4.250	4.230	4.208	4.166	4.164	4.142	4.140	4.139	4.122	4.120
0.235	0.236	0.238	0.240	0.240	0.241	0.242	0.242	0.243	0.243
10.796	10.786	10.772	10.748	10.743	10.727	10.723	10.719	10.716	10.713
2.54	2.55	2.56	2.58	2.58	2.59	2.59	2.59	2.6	2.6
2.504	2.514	2.528	2.552	2.557	2.573	2.577	2.581	2.584	2.587

【表 12】Lead 0ppm 數據



【表 13】
0ppm Lead
ND curve

(6) 綜合圖表



【表 14】
comparison
of different
concentration

(四) ND(尚未酸洗)與重金屬之共同放置反應(離心後)

經討論，本組認為若為奈米鑽石本身造成導電度變化則透過離心方式讓處於懸浮狀態的奈米粒子沉降(註 1)再進行導電率分析即可得到吸附重金屬與否的數據。

註 1:如研究步驟 5.所述，因純粹為 ND 飽和溶液的樣本，離心後上方溶液仍呈白色混濁，故不做導電率比較。

1. 導電度比較

(1) 個別數據

ND only - 200ppm Lead nitrate	5 days	precipitates	centrifugation							
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	10.304	10.020	9.845	9.751	9.498	9.255	9.097	8.875	8.736	8.525
conductivity for 200ppm Lead nitrate ND Cen	0.097	0.100	0.102	0.103	0.105	0.108	0.110	0.113	0.114	0.117
13.3-V for 200ppm Lead nitrate ND	1.141	1.176	1.191	1.209	1.238	1.268	1.292	1.319	1.331	1.365
V	12.159	12.124	12.109	12.091	12.062	12.032	12.008	11.981	11.969	11.935
I	1.18	1.21	1.23	1.24	1.27	1.30	1.32	1.35	1.37	1.40

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
8.329	8.137	8.069	8.066	7.945	7.831	7.830	7.771	7.769	7.655
0.120	0.123	0.124	0.124	0.126	0.128	0.128	0.129	0.129	0.131
1.390	1.420	1.439	1.443	1.462	1.475	1.476	1.488	1.491	1.511
11.91	11.88	11.861	11.857	11.838	11.825	11.824	11.812	11.809	11.789
1.43	1.46	1.47	1.47	1.49	1.51	1.51	1.52	1.52	1.54

【表 15】Lead 200ppm(ND-cen)

ND only - 100ppm Lead nitrate	5 days	centrifugation								
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	8.624	8.453	8.230	8.005	7.727	7.504	7.281	7.145	7.002	6.964
conductivity for 100ppm Lead nitrate ND Cen	0.116	0.118	0.122	0.125	0.129	0.133	0.137	0.140	0.143	0.144
I	1.382	1.407	1.441	1.477	1.524	1.564	1.606	1.633	1.662	1.670
V	11.918	11.893	11.859	11.823	11.776	11.736	11.694	11.667	11.638	11.63

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
6.856	6.710	6.596	6.455	6.324	6.193	6.007	5.938	5.856	5.775
0.146	0.149	0.152	0.155	0.158	0.161	0.166	0.168	0.171	0.173
1.693	1.725	1.751	1.784	1.816	1.849	1.898	1.917	1.940	1.963
11.607	11.575	11.549	11.516	11.484	11.451	11.402	11.383	11.36	11.337

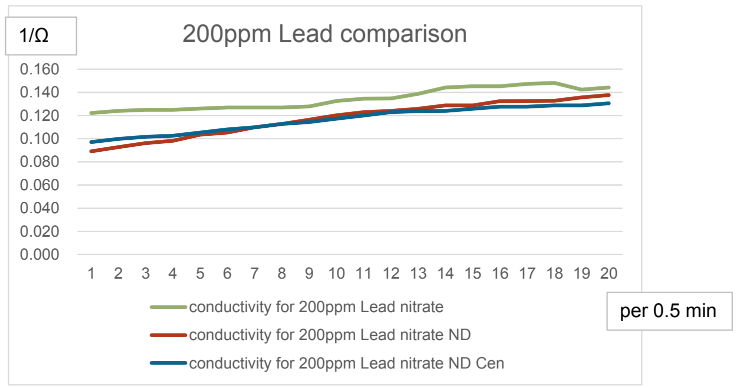
【表 16】Lead 100ppm(ND-cen)

ND only - 50ppm Lead nitrate	5 days	centrifugation								
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	12.642	12.358	11.950	11.409	11.124	10.909	10.498	10.213	10.024	9.760
conductivity for 50ppm Lead nitrate ND cen	0.079	0.081	0.084	0.088	0.090	0.092	0.095	0.098	0.100	0.102
V	12.389	12.358	12.308	12.208	12.236	12.218	12.178	12.154	12.129	12.102
I	0.980	1.000	1.030	1.07	1.100	1.120	1.160	1.19	1.21	1.24
13.3-V for 50ppm Lead nitrate ND	0.911	0.942	0.992	1.092	1.064	1.082	1.122	1.146	1.171	1.198

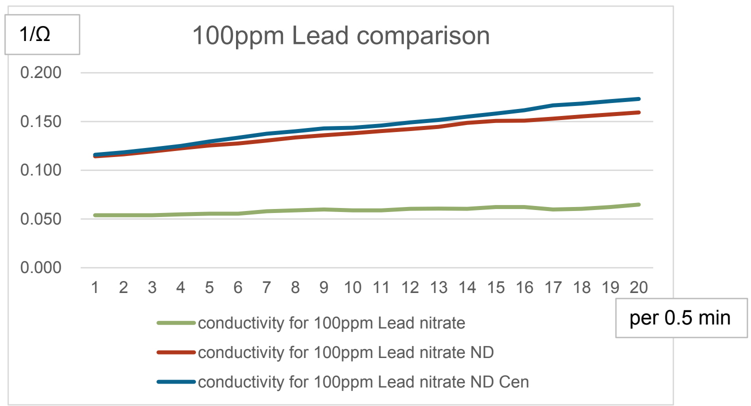
5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
9.509	9.421	9.176	8.809	8.534	8.329	8.069	7.828	7.550	7.382
0.105	0.106	0.109	0.114	0.117	0.120	0.124	0.128	0.132	0.135
12.076	12.059	12.021	11.98	11.947	11.91	11.861	11.82	11.778	11.737
1.27	1.28	1.31	1.36	1.4	1.43	1.47	1.51	1.56	1.59
1.224	1.241	1.279	1.320	1.353	1.390	1.439	1.480	1.522	1.563

【表 17】Lead 50ppm(ND-cen)

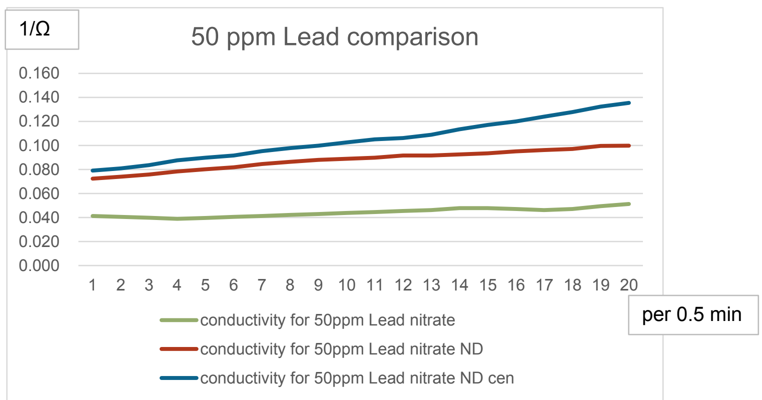
(2) 比較圖表



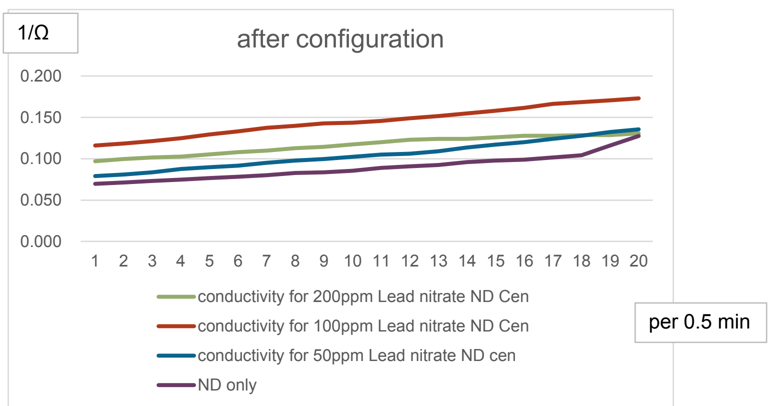
【表 18】200ppm Lead ND (centrifugation) , Lead ND and No ND's comparison



【表 19】100ppm Lead ND (centrifugation) , Lead ND and No ND's comparison



【表 20】50ppm Lead ND (centrifugation) , Lead ND and No ND's comparison



【表 21】total comparison of ND solution after centrifugation And ND only

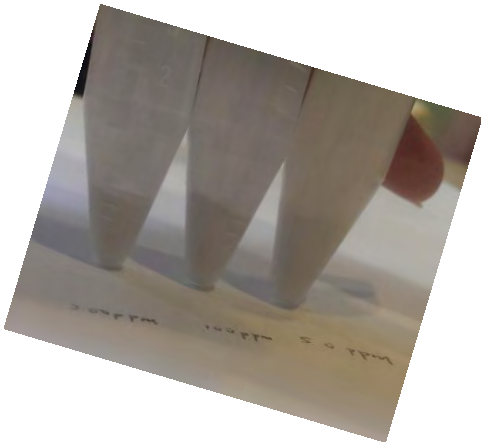
(3) 文字概述

對於上述圖表尤其是【表 19】、【表 21】所示，本組可更加確定奈米鑽石並無提升整體導電度之效，或可解釋為奈米鑽石尚無確切的導電性，【表 22】甚顯出樣本較奈米鑽石溶液導電度高的反應，而增加整體導電度應是未酸洗之奈米鑽石上吸附的其他官能基，可是奈米鑽石為交換樹脂。至於其吸附結構與平面顯影則需透過 XRD、TEM 與 SEM 來檢測，而此方面將於酸洗後的奈米鑽石實驗中提及並介紹不同重金屬離子與奈米鑽石的吸附情形。

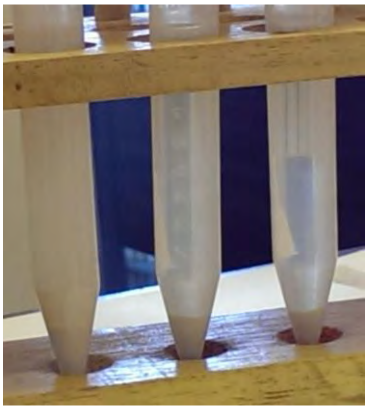
(五) ND(酸洗後之奈米鑽石 ND-COOH)吸附重金屬外觀、導電度、結構與表面顯像

1.肉眼觀察

(1) 硝酸鉛



【圖 44】Pb & ND-COOH (20 minutes)

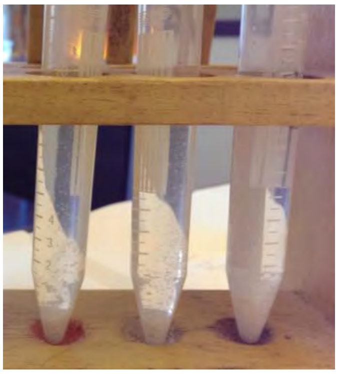


【圖 45】Pb & ND-COOH (1 day)

(2) 硝酸鎳

【圖 46】Ni & ND-COOH (1 day)

(3) 硝酸锌



【圖 47】Zn & ND-COOH (1 day)

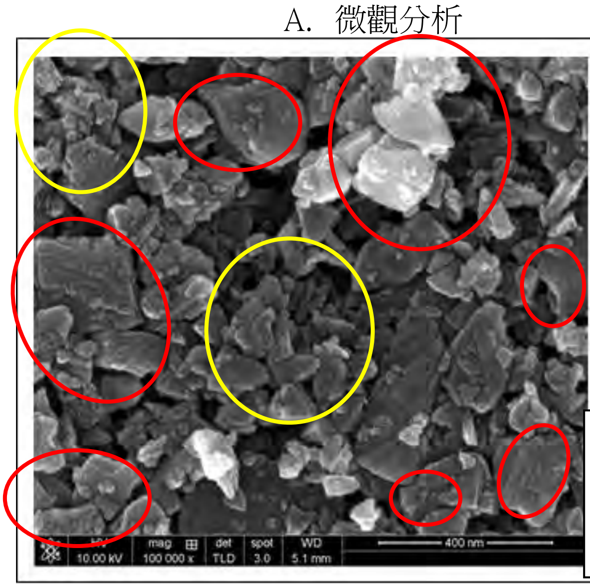
(3) 觀察概述

此批樣本沉澱較為乾淨，上方溶液溶液清澈，應為此次實驗有固定奈米鑽石量(約為 500~1000 µg/ml)所保持。

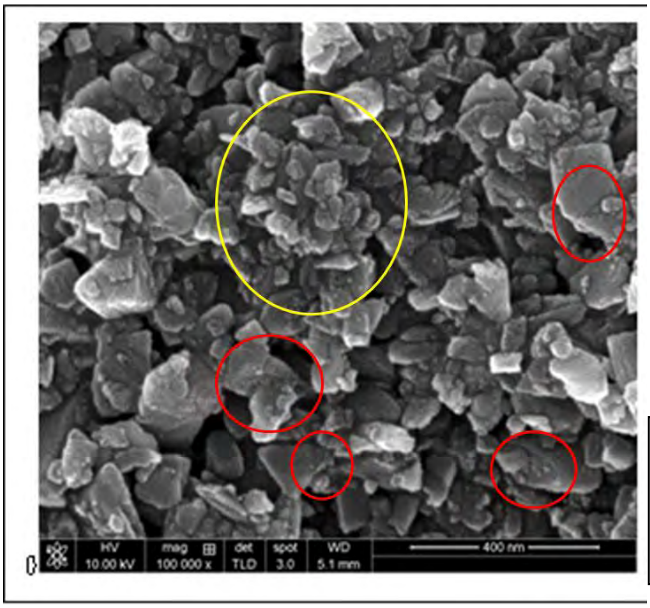
2.SEM 下樣本微觀

(1) 硝酸鉛

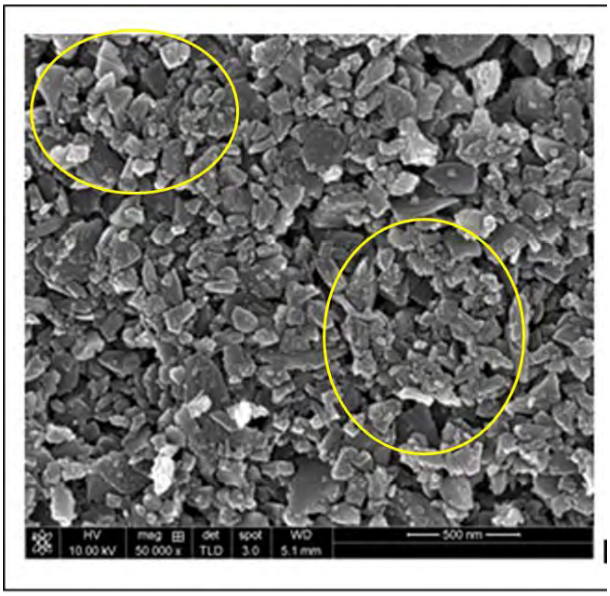
A. 微觀分析



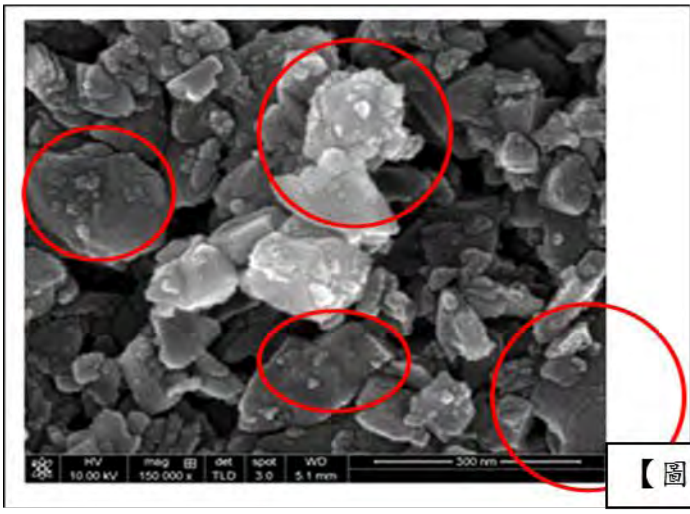
【圖 48】
$Pb(NO_3)_2$ SEM
100000*



【圖 49】
$Pb(NO_3)_2$ SEM
100000*



【圖 50】
$Pb(NO_3)_2$ SEM
50000*

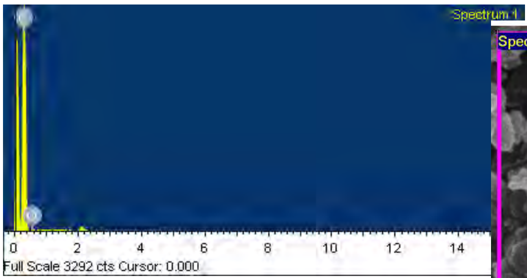


【圖51】$Pb(NO_3)_2$ SEM 150000*

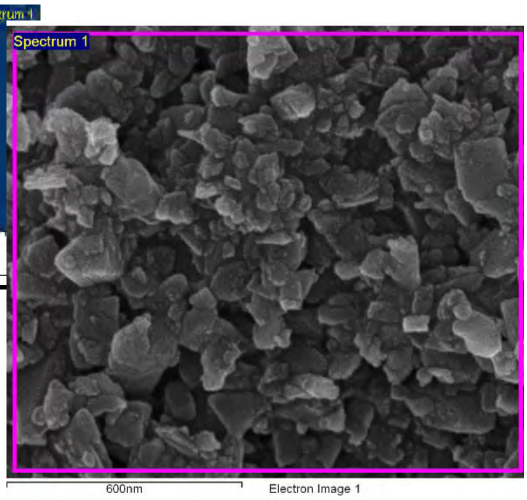
B.　文字敘述

從紅色圓圈所框出之處有明顯的小型沉澱聚集，並且尚有較多三角扇形沉澱，小型鑽石主要聚於扇形邊緣居多，其餘皆附著於其餘形狀內。黃色圓圈所圈出範圍，最能見其大型聚集狀況，固可先推測重金屬離子確實有聚集功能。

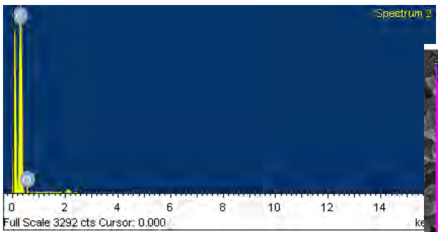
C.　元素分析



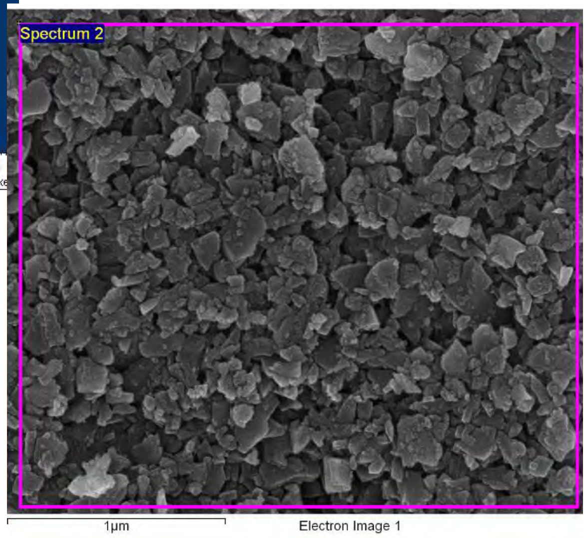
Element	Weight %	Atomic %
C K	98.05	98.53
O K	1.95	1.47
Totals	100.00	



【表 22】Lead 600nm scale range



Element	Weight%	Atomic%
C K	97.18	97.87
O K	2.82	2.13
Totals	100.00	



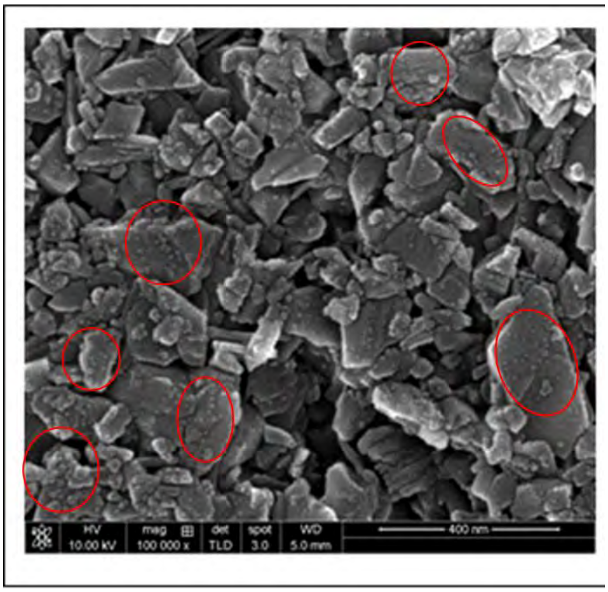
【表 23】Lead 1 μm scale range

a.　此數據顯示不論間距大小 C，O 比例相似。

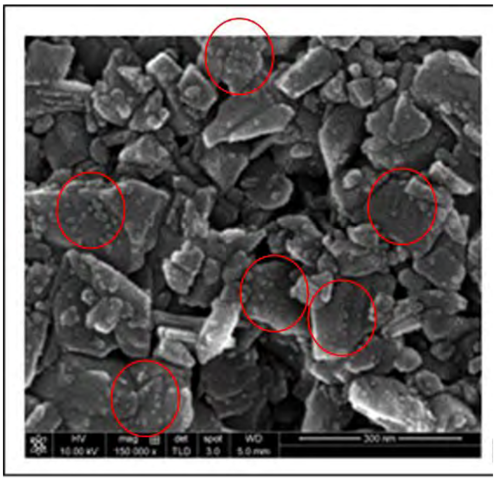
b.　並無 Pb 以元素狀態呈現。

(2). 硝酸鋅

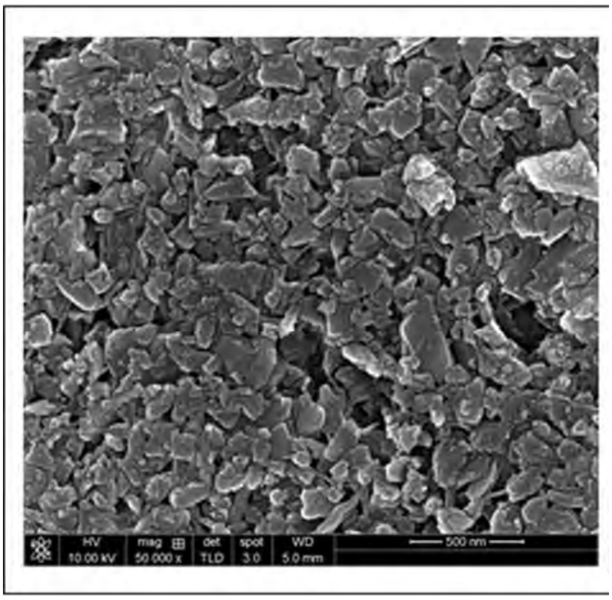
A. 微觀分析



【圖 52】
$Zn(NO_3)_2$ SEM
100000*



【圖 53】
$Zn(NO_3)_2$ SEM
150000*

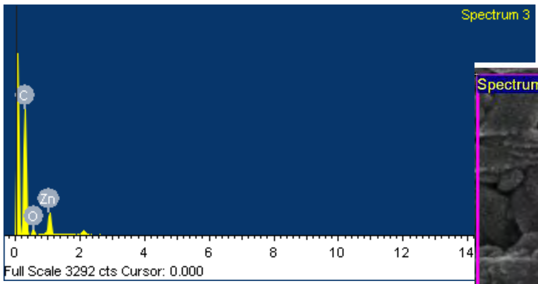


【圖 54】
$Zn(NO_3)_2$ SEM
50000*

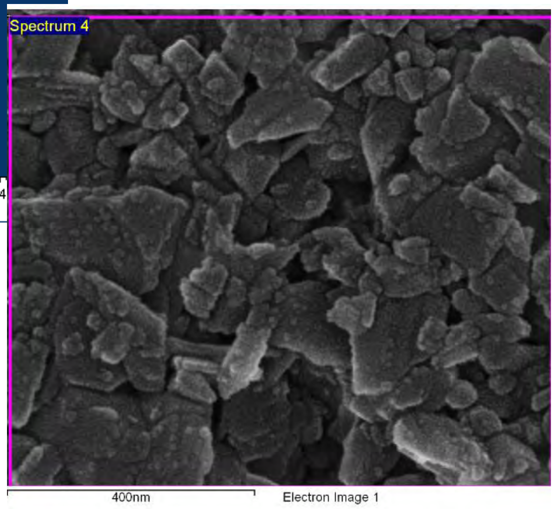
B.　文字敘述

從紅色圈出處可發現有許多小型奈米鑽石附著於其他大型奈米鑽石上。而耐名鑽石得形狀亦不像 Pb 的扇形相似。大型沉聚少，小型附著顯著為多。

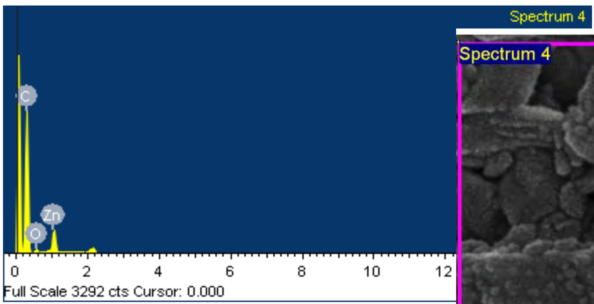
C.元素分析



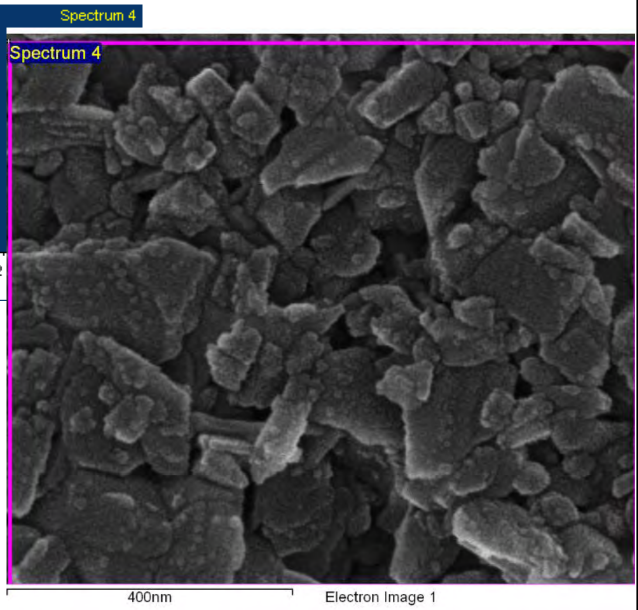
Element	Weight%	Atomic%
C K	80.36	92.22
O K	5.60	4.82
Zn L	14.04	2.96
Totals	100.00	



【表 24】Zinc 1 μ m scale range



Element	Weight%	Atomic%
C K	81.72	93.09
O K	4.77	4.08
Zn L	13.50	2.83
Totals	100.00	

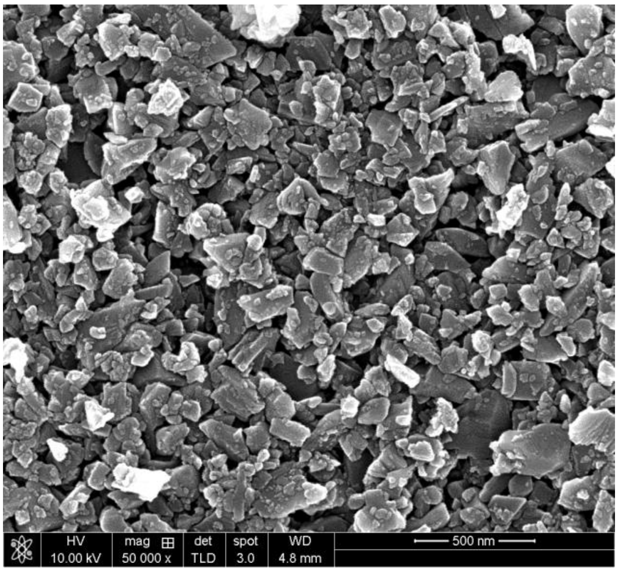


【表 25】Zinc 400nm scale range

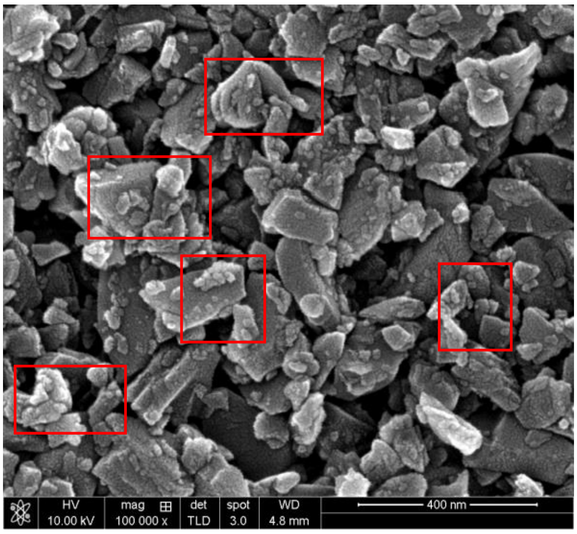
1. Zn 有元素狀態，應是 ZnO
2. Zn 的比例不因不同尺度而有所改變。

(3). 硝酸鎳

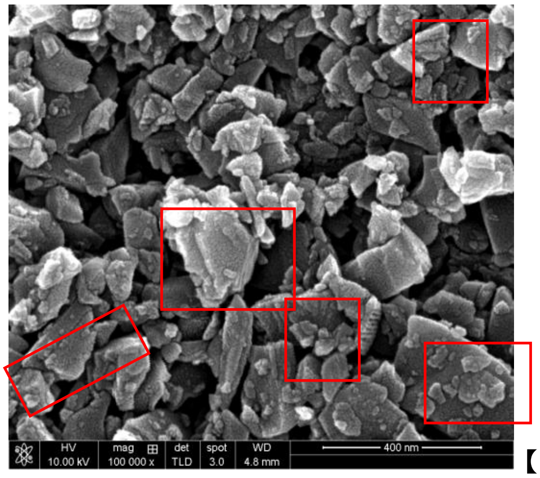
A. 微觀分析



【圖 55】$Ni(NO_3)_2$ ND under SEM 50000*



【圖 56】$Ni(NO_3)_2$ ND under SEM 100000*

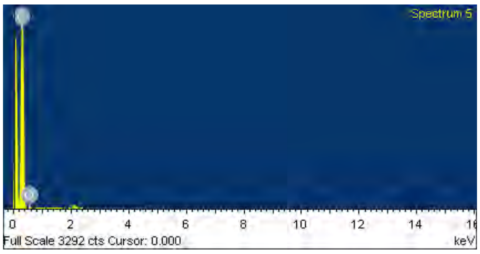


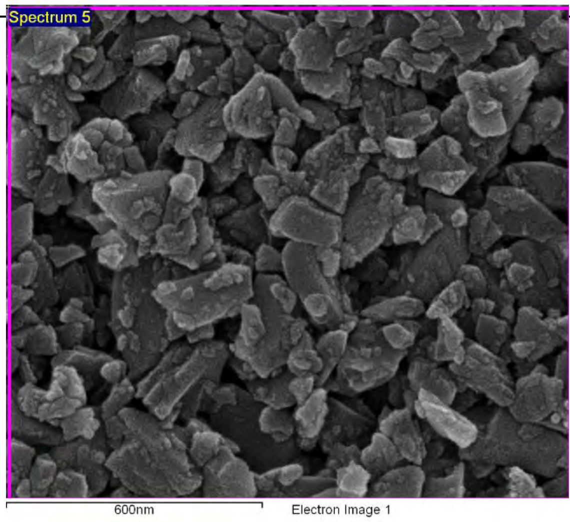
【圖 57】$Ni(NO_3)_2$ ND under SEM 100000*

B.文字敘述

在硝酸鎳的圖像中，可針對其吸附顆粒大小作分析，經本組觀察可發現紅色框處尚有許多較為大型沉澱(由小沉澱聚合而成)，其餘多為大型沉澱互相吸引。

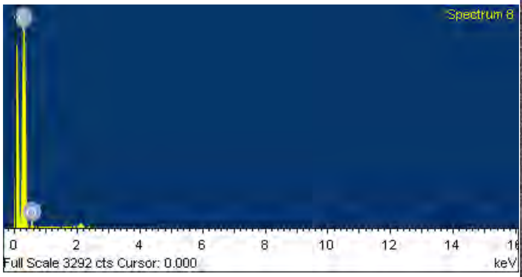
C.元素分析

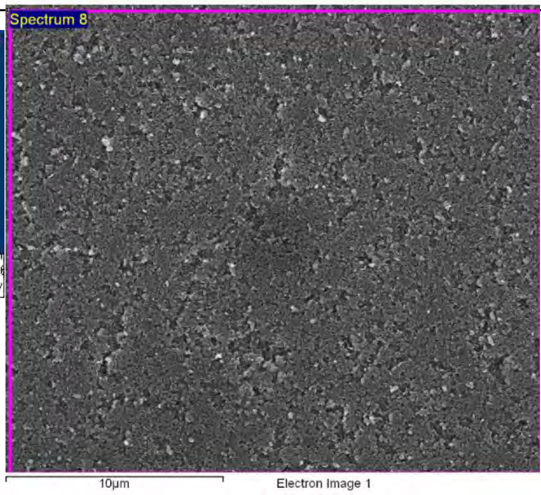




Element	Weight%	Atomic%
C K	97.63	98.21
O K	2.37	1.79
Totals	100.00	

【表 26】Nickel 600nm scale range





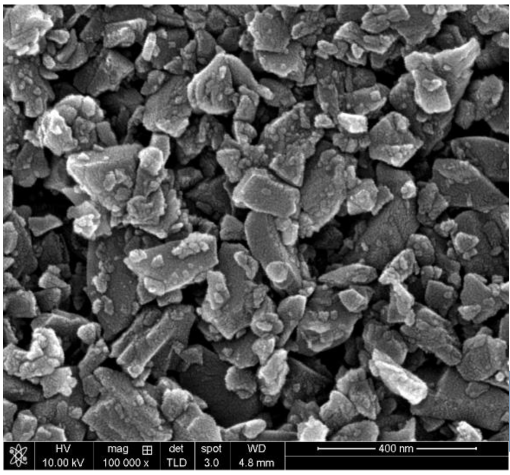
Element	Weight%	Atomic%
C K	96.49	97.34
O K	3.51	2.66
Totals	100.00	

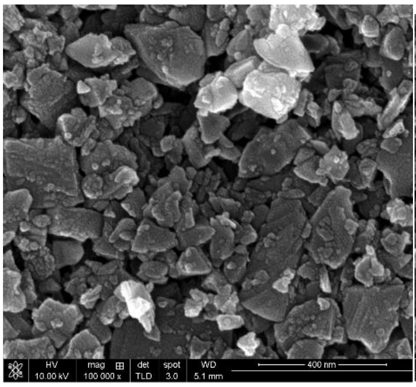
【表 27】Nickel 10 μ m scale range

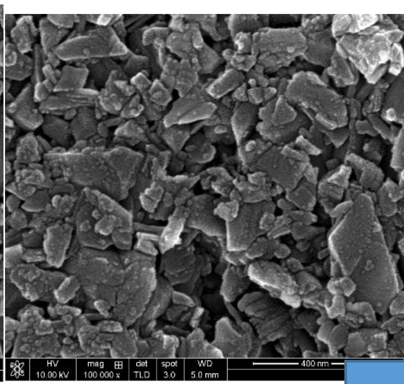
a.數據顯示 C、O 比例不因範圍而異。

b.與其他元素所做比例相似。

(4).互相比較







三者有不同聚集方式與排列，可對其排列原因作探討。
且鉛的聚集較為明顯，其餘離子可到結論(六)1.(3)微觀分析進行對照與探討。

3. 導電度測量

(1) 硝酸鉛導電數據與曲線

ND(-COOH) - 200ppm Lead nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	14.549	14.200	14.020	13.530	12.931	12.645	12.242	12.114	11.615	11.273
onductivity for 200ppm Lead nitrate ND(-COOH	0.069	0.070	0.071	0.074	0.077	0.079	0.082	0.083	0.086	0.089
V	12.512	12.496	12.478	12.448	12.414	12.392	12.364	12.356	12.312	12.288
I	0.860	0.880	0.890	0.92	0.960	0.980	1.010	1.02	1.06	1.09
13.3-V for 200ppm Lead nitrate ND(-COOH)	0.788	0.804	0.822	0.852	0.886	0.908	0.936	0.944	0.988	1.012

	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
	11.268	11.159	10.835	10.629	10.630	10.624	10.628	10.928	10.931	10.929	10.828	10.630	10.531	10.428	10.330	10.242	10.237	10.142	10.238	10.332
	0.089	0.090	0.092	0.094	0.094	0.094	0.094	0.092	0.091	0.091	0.092	0.094	0.095	0.096	0.097	0.098	0.098	0.099	0.098	0.097
	12.282	12.275	12.243	12.223	12.225	12.218	12.222	12.239	12.243	12.241	12.236	12.224	12.216	12.201	12.189	12.188	12.182	12.17	12.183	12.192
	1.09	1.1	1.13	1.15	1.15	1.15	1.15	1.12	1.12	1.12	1.13	1.15	1.16	1.17	1.18	1.19	1.19	1.2	1.19	1.18
	1.018	1.025	1.057	1.077	1.075	1.082	1.078	1.061	1.057	1.059	1.064	1.076	1.084	1.099	1.111	1.112	1.118	1.130	1.117	1.108

	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
	10.245	10.243	10.327	10.329	10.241	10.332	10.335	10.429	10.533	10.731	10.630	10.428	10.240	10.144	9.880	9.702	9.616	9.530	9.446	9.363
	0.098	0.098	0.097	0.097	0.098	0.097	0.097	0.096	0.095	0.093	0.094	0.096	0.098	0.099	0.101	0.103	0.104	0.105	0.106	0.107
	12.191	12.189	12.186	12.188	12.187	12.192	12.195	12.202	12.218	12.233	12.225	12.201	12.186	12.173	12.152	12.127	12.116	12.103	12.091	12.078
	1.19	1.19	1.18	1.18	1.19	1.18	1.18	1.17	1.16	1.14	1.15	1.17	1.19	1.2	1.23	1.25	1.26	1.27	1.28	1.29
	1.109	1.111	1.114	1.112	1.113	1.108	1.105	1.098	1.082	1.067	1.075	1.099	1.114	1.127	1.148	1.173	1.184	1.197	1.209	1.222

	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
	9.203	9.038	9.035	8.956	8.952	8.949	8.876	8.802	8.727	8.654
	0.109	0.111	0.111	0.112	0.112	0.112	0.113	0.114	0.115	0.116
	12.056	12.021	12.016	12.001	11.996	11.991	11.982	11.971	11.956	11.943
	1.31	1.33	1.33	1.34	1.34	1.34	1.35	1.36	1.37	1.38
	1.244	1.279	1.284	1.299	1.304	1.309	1.318	1.329	1.344	1.357

【表 28】Lead 200ppm with ND-COOH

ND(-COOH) - 100ppm Lead nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	39.545	39.530	39.545	38.326	36.153	37.189	37.203	37.229	36.136	36.142
onductivity for 100ppm Lead nitrate ND(-COOH	0.025	0.025	0.025	0.026	0.028	0.027	0.027	0.027	0.028	0.028
V	13.050	13.045	13.050	13.031	13.015	13.016	13.021	13.03	13.009	13.011
I	0.330	0.330	0.330	0.34	0.360	0.350	0.350	0.35	0.36	0.36
13.3-V for 100ppm Lead nitrate ND(-COOH)	0.250	0.255	0.250	0.269	0.285	0.284	0.279	0.270	0.291	0.289

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
36.144	36.139	37.203	37.200	36.150	36.136	36.133	36.131	36.136	36.150	36.147	36.142	36.153	36.150	36.147	36.142	37.203	37.214	37.217	37.229
0.028	0.028	0.027	0.027	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.027	0.027	0.027	0.027
13.012	13.01	13.021	13.02	13.014	13.009	13.008	13.007	13.009	13.014	13.013	13.011	13.015	13.014	13.013	13.011	13.021	13.025	13.026	13.03
0.36	0.36	0.35	0.35	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.35
0.288	0.290	0.279	0.280	0.286	0.291	0.292	0.293	0.291	0.286	0.287	0.289	0.285	0.286	0.287	0.289	0.279	0.275	0.274	0.270

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
38.326	38.329	38.335	38.338	38.344	38.347	39.518	38.350	38.344	38.338	38.332	38.329	38.334	38.344	38.350	39.518	39.521	39.527	39.530	39.536
0.026	0.026	0.026	0.026	0.026	0.026	0.025	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.025	0.025	0.025	0.025	0.025
13.031	13.032	13.034	13.035	13.037	13.038	13.041	13.039	13.037	13.035	13.033	13.032	13.0334	13.037	13.039	13.041	13.042	13.044	13.045	13.047
0.34	0.34	0.34	0.34	0.34	0.34	0.33	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33	0.33	0.33
0.269	0.268	0.266	0.265	0.263	0.262	0.259	0.261	0.263	0.265	0.267	0.268	0.267	0.263	0.261	0.259	0.258	0.256	0.255	0.253

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
39.542	39.548	40.791	40.797	40.800	40.806	40.809	40.816	42.139	42.142
0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.024	0.024
13.049	13.051	13.053	13.055	13.056	13.058	13.059	13.061	13.063	13.064
0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.32	0.31	0.31
0.251	0.249	0.247	0.245	0.244	0.242	0.241	0.239	0.237	0.236

【表 29】Lead 100ppm with ND-COOH

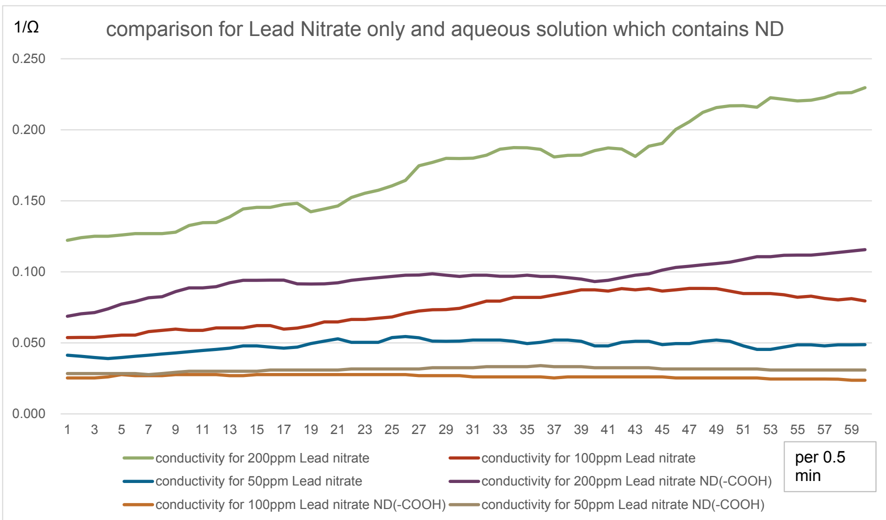
ND(-COOH) - 50ppm Lead nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	35.151	35.146	35.138	35.151	35.138	35.157	36.147	35.132	34.187	33.295
onductivity for 50ppm Lead nitrate ND(-COOH	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.029	0.030
V	13.006	13.004	13.001	13.006	13.001	13.008	13.013	12.999	12.991	12.985
I	0.370	0.370	0.370	0.37	0.370	0.370	0.360	0.37	0.38	0.39
13.3-V for 50ppm Lead nitrate ND(-COOH)	0.294	0.296	0.299	0.294	0.299	0.292	0.287	0.301	0.309	0.315

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
33.285	33.282	33.277	33.272	33.264	32.425	32.423	32.408	32.403	32.400	32.395	31.600	31.593	31.590	31.585	31.583	31.578	30.817	30.812	30.807
0.030	0.030	0.030	0.030	0.030	0.031	0.031	0.031	0.031	0.031	0.031	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
12.981	12.98	12.978	12.976	12.973	12.97	12.969	12.963	12.961	12.96	12.958	12.956	12.953	12.952	12.95	12.949	12.947	12.943	12.941	12.939
0.39	0.39	0.39	0.39	0.39	0.4	0.4	0.4	0.4	0.4	0.4	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.42	0.42
0.319	0.320	0.322	0.324	0.327	0.330	0.331	0.337	0.339	0.340	0.342	0.344	0.347	0.348	0.350	0.351	0.353	0.357	0.359	0.361

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
30.802	30.079	30.070	30.065	30.063	29.373	30.060	30.065	30.072	30.798	30.800	30.805	30.807	30.814	31.573	31.578	31.580	31.583	31.588	31.590
0.032	0.033	0.033	0.033	0.033	0.034	0.033	0.033	0.033	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
12.937	12.934	12.93	12.928	12.927	12.924	12.926	12.928	12.931	12.935	12.936	12.938	12.939	12.942	12.945	12.947	12.948	12.949	12.951	12.952
0.42	0.43	0.43	0.43	0.43	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.42	0.41	0.41	0.41	0.41	0.41	0.41
0.363	0.366	0.370	0.372	0.373	0.376	0.374	0.372	0.369	0.365	0.364	0.362	0.361	0.358	0.355	0.353	0.352	0.351	0.349	0.348

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
31.595	31.605	32.403	32.405	32.410	32.413	32.418	32.420	32.415	32.408
0.032	0.032	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
12.954	12.958	12.961	12.962	12.964	12.965	12.967	12.968	12.966	12.963
0.41	0.41	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.346	0.342	0.339	0.338	0.336	0.335	0.333	0.332	0.334	0.337

【表 30】Lead 50ppm with ND-COOH



【表 31】 Lead with ND-COOD versus Lead only

(2) 硝酸鎳導電數據與曲線

ND(-COOH) - 200ppm Nickel nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	7.187	7.140	7.136	7.139	7.187	7.136	7.135	7.091	7.135	7.089
nductivity for 200ppm Nickel nitrate ND(-COO	0.139	0.140	0.140	0.140	0.139	0.140	0.140	0.141	0.140	0.141
V	11.715	11.710	11.703	11.708	11.715	11.703	11.702	11.7	11.701	11.697
I	1.630	1.640	1.640	1.64	1.630	1.640	1.640	1.65	1.64	1.65
13.3-V for 200ppm Nickel nitrate ND(-COOH)	1.585	1.590	1.597	1.592	1.585	1.597	1.598	1.600	1.599	1.603

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
7.088	7.085	7.040	7.039	7.037	7.036	6.991	6.989	6.988	6.987	6.943	6.942	6.940	6.938	6.935	6.893	6.888	6.883	6.842	6.840
0.141	0.141	0.142	0.142	0.142	0.142	0.143	0.143	0.143	0.143	0.144	0.144	0.144	0.144	0.144	0.145	0.145	0.145	0.146	0.146
11.695	11.691	11.687	11.685	11.681	11.679	11.675	11.672	11.67	11.668	11.665	11.6625	11.66	11.656	11.65	11.649	11.641	11.632	11.631	11.628
1.65	1.65	1.66	1.66	1.66	1.66	1.67	1.67	1.67	1.67	1.68	1.68	1.68	1.68	1.68	1.69	1.69	1.69	1.7	1.7
1.605	1.609	1.613	1.615	1.619	1.621	1.625	1.628	1.630	1.632	1.635	1.638	1.640	1.644	1.650	1.651	1.659	1.668	1.669	1.672

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
6.838	6.838	6.791	6.789	6.785	6.739	6.692	6.603	6.556	6.508	6.503	6.462	6.460	6.420	6.415	6.373	6.368	6.366	6.364	6.321
0.146	0.146	0.147	0.147	0.147	0.148	0.149	0.151	0.153	0.154	0.154	0.155	0.155	0.156	0.156	0.157	0.157	0.157	0.157	0.158
11.625	11.624	11.613	11.61	11.603	11.591	11.578	11.556	11.538	11.519	11.511	11.502	11.498	11.491	11.482	11.471	11.462	11.458	11.455	11.441
1.7	1.7	1.71	1.71	1.71	1.72	1.73	1.75	1.76	1.77	1.77	1.78	1.78	1.79	1.79	1.8	1.8	1.8	1.8	1.81
1.675	1.676	1.687	1.690	1.697	1.709	1.722	1.744	1.762	1.781	1.789	1.798	1.802	1.809	1.818	1.829	1.838	1.842	1.845	1.859

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
6.319	6.278	6.236	6.231	6.194	6.152	6.149	6.113	6.110	6.074
0.158	0.159	0.160	0.160	0.161	0.163	0.163	0.164	0.164	0.165
11.437	11.426	11.411	11.403	11.397	11.382	11.376	11.37	11.364	11.358
1.81	1.82	1.83	1.83	1.84	1.85	1.85	1.86	1.86	1.87
1.863	1.874	1.889	1.897	1.903	1.918	1.924	1.930	1.936	1.942

【表 32】Nickel 200ppm with ND-COOH

ND(-COOH) - 100ppm Nickel nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	13.057	13.202	13.209	13.354	13.361	13.511	13.359	13.209	13.204	13.203
nductivity for 100ppm Nickel nitrate ND(-COO	0.077	0.076	0.076	0.075	0.075	0.074	0.075	0.076	0.076	0.076
V	12.404	12.410	12.416	12.419	12.426	12.430	12.424	12.416	12.412	12.411
I	0.950	0.940	0.940	0.93	0.930	0.920	0.930	0.94	0.94	0.94
13.3-V for 100ppm Nickel nitrate ND(-COOH)	0.896	0.890	0.884	0.881	0.874	0.870	0.876	0.884	0.888	0.889

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
13.201	13.060	13.056	13.055	13.057	13.054	13.053	13.201	13.204	13.209	13.355	13.356	13.359	13.201	13.653	12.911	12.907	12.904	12.767	12.76
0.076	0.077	0.077	0.077	0.077	0.077	0.077	0.076	0.076	0.076	0.075	0.075	0.075	0.076	0.073	0.077	0.077	0.077	0.078	0.078
12.409	12.407	12.403	12.402	12.404	12.401	12.4	12.409	12.412	12.416	12.42	12.421	12.424	12.409	12.97	12.395	12.391	12.388	12.384	12.38
0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.94	0.94	0.93	0.93	0.93	0.94	0.95	0.96	0.96	0.96	0.97	0.9
0.891	0.893	0.897	0.898	0.896	0.899	0.900	0.891	0.888	0.884	0.880	0.879	0.876	0.891	0.330	0.905	0.909	0.912	0.916	0.91

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
12.763	12.761	12.614	12.605	12.471	12.460	12.328	12.316	12.188	12.185	12.058	12.052	12.046	11.923	11.922	11.920	11.917	11.917	11.914	11.796
0.078	0.078	0.079	0.079	0.080	0.080	0.081	0.081	0.082	0.082	0.083	0.083	0.083	0.084	0.084	0.084	0.084	0.084	0.084	0.085
12.38	12.378	12.362	12.353	12.346	12.335	12.328	12.316	12.31	12.307	12.299	12.293	12.287	12.281	12.28	12.278	12.275	12.274	12.271	12.268
0.97	0.97	0.98	0.98	0.99	0.99	1	1	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.04
0.920	0.922	0.938	0.947	0.954	0.965	0.972	0.984	0.990	0.993	1.001	1.007	1.013	1.019	1.020	1.022	1.025	1.026	1.029	1.032

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
11.793	11.795	11.669	11.671	11.668	11.666	11.664	11.550	11.549	11.548
0.085	0.085	0.086	0.086	0.086	0.086	0.086	0.087	0.087	0.087
12.265	12.267	12.252	12.255	12.251	12.249	12.247	12.243	12.242	12.241
1.04	1.04	1.05	1.05	1.05	1.05	1.05	1.06	1.06	1.06
1.035	1.033	1.048	1.045	1.049	1.051	1.053	1.057	1.058	1.059

【表 33】Nickel 100ppm with ND-COOH

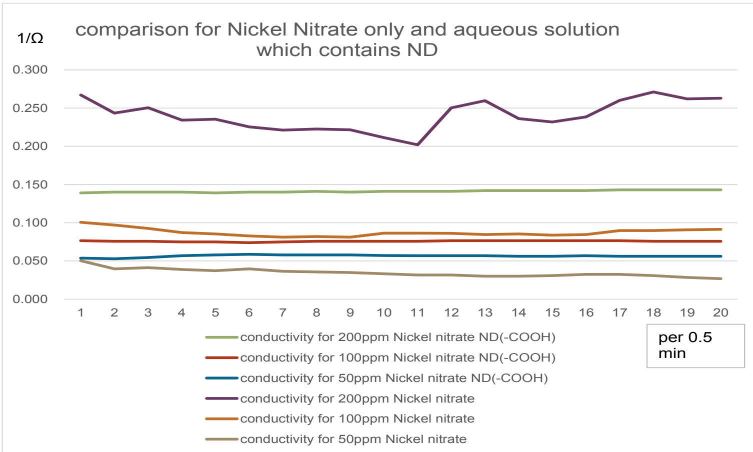
ND (-COOH) - 50ppm Nickel nitrate	1.5 days									
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	18.646	18.933	18.357	17.550	17.301	17.051	17.292	17.297	17.300	17.543
onductivity for 50ppm Nickel nitrate ND(-COOI	0.054	0.053	0.054	0.057	0.058	0.059	0.058	0.058	0.058	0.057
V	12.679	12.685	12.666	12.636	12.630	12.618	12.623	12.627	12.629	12.631
I	0.680	0.670	0.690	0.72	0.730	0.740	0.730	0.73	0.73	0.72
13.3-V for 50ppm Nickel nitrate ND(-COOH)	0.621	0.615	0.634	0.664	0.670	0.682	0.677	0.673	0.671	0.669

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
17.550	17.551	17.553	17.804	17.807	17.556	17.810	17.806	17.815	17.807	17.554	17.295	17.054	17.047	16.812	16.800	16.567	16.557	16.545	16.314
0.057	0.057	0.057	0.056	0.056	0.057	0.056	0.056	0.056	0.056	0.057	0.058	0.059	0.059	0.059	0.060	0.060	0.060	0.060	0.061
12.636	12.637	12.638	12.641	12.643	12.64	12.645	12.642	12.649	12.643	12.639	12.625	12.62	12.615	12.609	12.6	12.591	12.583	12.574	12.562
0.72	0.72	0.72	0.71	0.71	0.72	0.71	0.71	0.71	0.71	0.72	0.73	0.74	0.74	0.75	0.75	0.76	0.76	0.76	0.77
0.664	0.663	0.662	0.659	0.657	0.660	0.655	0.658	0.651	0.657	0.661	0.675	0.680	0.685	0.691	0.700	0.709	0.717	0.726	0.738

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
16.308	16.087	16.072	15.861	15.854	15.846	15.643	15.641	15.645	15.848	15.854	15.853	15.849	15.645	15.447	15.446	15.251	15.252	15.248	15.059
0.061	0.062	0.062	0.063	0.063	0.063	0.064	0.064	0.064	0.063	0.063	0.063	0.063	0.064	0.065	0.065	0.066	0.066	0.066	0.066
12.557	12.548	12.536	12.53	12.525	12.518	12.514	12.513	12.516	12.52	12.525	12.524	12.521	12.516	12.512	12.511	12.506	12.507	12.503	12.499
0.77	0.78	0.78	0.79	0.79	0.79	0.8	0.8	0.8	0.79	0.79	0.79	0.79	0.8	0.81	0.81	0.82	0.82	0.82	0.83
0.743	0.752	0.764	0.770	0.775	0.782	0.786	0.787	0.784	0.780	0.775	0.776	0.779	0.784	0.788	0.789	0.794	0.793	0.797	0.801

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
15.058	15.245	15.054	15.052	14.870	15.051	14.868	14.861	14.682	14.674
0.066	0.066	0.066	0.066	0.067	0.066	0.067	0.067	0.068	0.068
12.498	12.501	12.495	12.493	12.491	12.492	12.489	12.483	12.48	12.473
0.83	0.82	0.83	0.83	0.84	0.83	0.84	0.84	0.85	0.85
0.802	0.799	0.805	0.807	0.809	0.808	0.811	0.817	0.820	0.827

【表 34】Nickel 50ppm with ND-COOH



【表 35】Nickel with ND-COOD versus Lead only

(3) 硝酸锌導電數據與曲線

ND (-COOH) - 200ppm Zinc nitrate										
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	5.903	5.797	5.696	5.631	5.562	5.463	5.400	5.334	5.304	5.273
onductivity for 200ppm Zinc nitrate ND(-COOH	0.169	0.172	0.176	0.178	0.180	0.183	0.185	0.187	0.189	0.190
V	11.393	11.363	11.336	11.319	11.291	11.254	11.232	11.201	11.191	11.178
I	1.930	1.960	1.990	2.01	2.030	2.060	2.080	2.1	2.11	2.12
13.3-V for 200ppm Zinc nitrate ND(-COOH)	1.907	1.937	1.964	1.981	2.009	2.046	2.068	2.099	2.109	2.122

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
5.212	5.154	5.124	5.069	5.016	4.961	4.934	4.881	4.804	4.729	4.634	4.587	4.496	4.423	4.356	4.334	4.243	4.164	4.090	4.027
0.192	0.194	0.195	0.197	0.199	0.202	0.203	0.205	0.208	0.211	0.216	0.218	0.222	0.226	0.230	0.231	0.236	0.240	0.244	0.248
11.153	11.132	11.119	11.101	11.086	11.063	11.053	11.031	11.001	10.972	10.937	10.916	10.881	10.836	10.804	10.791	10.736	10.701	10.676	10.631
2.14	2.16	2.17	2.19	2.21	2.23	2.24	2.26	2.29	2.32	2.36	2.38	2.42	2.45	2.48	2.49	2.53	2.57	2.61	2.64
2.147	2.168	2.181	2.199	2.214	2.237	2.247	2.269	2.299	2.328	2.363	2.384	2.419	2.464	2.496	2.509	2.564	2.599	2.624	2.669

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
3.988	3.930	3.856	3.803	3.747	3.693	3.642	3.610	3.558	3.522	3.505	3.476	3.458	3.423	3.394	3.365	3.336	3.290	3.244	3.229
0.251	0.254	0.259	0.263	0.267	0.271	0.275	0.277	0.281	0.284	0.285	0.288	0.289	0.292	0.295	0.297	0.300	0.304	0.308	0.310
10.609	10.571	10.526	10.497	10.453	10.413	10.381	10.36	10.319	10.283	10.271	10.253	10.236	10.201	10.182	10.161	10.142	10.101	9.991	9.978
2.66	2.69	2.73	2.76	2.79	2.82	2.85	2.87	2.9	2.92	2.93	2.95	2.96	2.98	3	3.02	3.04	3.07	3.08	3.09
2.691	2.729	2.774	2.803	2.847	2.887	2.919	2.940	2.981	3.017	3.029	3.047	3.064	3.099	3.118	3.139	3.158	3.199	3.309	3.322

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
3.195	3.153	3.124	3.071	3.045	3.031	3.017	2.965	2.940	2.915
0.313	0.317	0.320	0.326	0.328	0.330	0.331	0.337	0.340	0.343
9.936	9.901	9.872	9.828	9.804	9.79	9.776	9.724	9.701	9.679
3.11	3.14	3.16	3.2	3.22	3.23	3.24	3.28	3.3	3.32
3.364	3.399	3.428	3.472	3.496	3.510	3.524	3.576	3.599	3.621

【表 36】Zinc 200ppm with ND-COOH

ND (-COOH) - 100ppm Zinc nitrate										
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	6.933	6.933	6.978	6.934	6.981	6.983	6.984	6.986	7.030	7.031
onductivity for 100ppm Zinc nitrate ND(-COOH	0.144	0.144	0.143	0.144	0.143	0.143	0.143	0.143	0.142	0.142
V	11.648	11.647	11.653	11.649	11.659	11.661	11.663	11.667	11.67	11.672
I	1.680	1.680	1.670	1.68	1.670	1.670	1.670	1.67	1.66	1.66
13.3-V for 100ppm Zinc nitrate ND(-COOH)	1.652	1.653	1.647	1.651	1.641	1.639	1.637	1.633	1.630	1.628

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
7.033	7.036	7.082	7.085	7.087	7.134	7.085	7.079	7.029	7.020	6.977	6.972	6.927	6.921	6.878	6.871	6.828	6.822	6.778	6.727
0.142	0.142	0.141	0.141	0.141	0.140	0.141	0.141	0.142	0.142	0.143	0.143	0.144	0.144	0.145	0.146	0.146	0.147	0.148	0.149
11.675	11.679	11.685	11.691	11.694	11.699	11.69	11.681	11.668	11.653	11.651	11.643	11.637	11.628	11.624	11.612	11.608	11.597	11.59	11.571
1.66	1.66	1.65	1.65	1.65	1.64	1.65	1.65	1.66	1.66	1.67	1.67	1.68	1.68	1.69	1.69	1.7	1.7	1.71	1.72
1.625	1.621	1.615	1.609	1.606	1.601	1.610	1.619	1.632	1.647	1.649	1.657	1.663	1.672	1.676	1.688	1.692	1.703	1.710	1.729

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
6.680	6.634	6.546	6.501	6.456	6.409	6.408	6.367	6.274	6.233	6.191	6.186	6.151	6.109	6.070	6.031	5.993	5.917	5.881	5.877
0.150	0.151	0.153	0.154	0.155	0.156	0.156	0.157	0.159	0.160	0.162	0.162	0.163	0.164	0.165	0.166	0.167	0.169	0.170	0.170
11.556	11.543	11.521	11.507	11.491	11.473	11.471	11.46	11.419	11.407	11.391	11.382	11.379	11.363	11.351	11.338	11.326	11.301	11.292	11.283
1.73	1.74	1.76	1.77	1.78	1.79	1.79	1.8	1.82	1.83	1.84	1.84	1.85	1.86	1.87	1.88	1.89	1.91	1.92	1.92
1.744	1.757	1.779	1.793	1.809	1.827	1.829	1.840	1.881	1.893	1.909	1.918	1.921	1.937	1.949	1.962	1.974	1.999	2.008	2.017

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
5.840	5.801	5.765	5.729	5.691	5.657	5.593	5.559	5.523	5.489
0.171	0.172	0.173	0.175	0.176	0.177	0.179	0.180	0.181	0.182
11.271	11.253	11.241	11.229	11.212	11.201	11.186	11.173	11.156	11.143
1.93	1.94	1.95	1.96	1.97	1.98	2	2.01	2.02	2.03
2.029	2.047	2.059	2.071	2.088	2.099	2.114	2.127	2.144	2.157

【表 37】Zinc 100ppm with ND-COOH

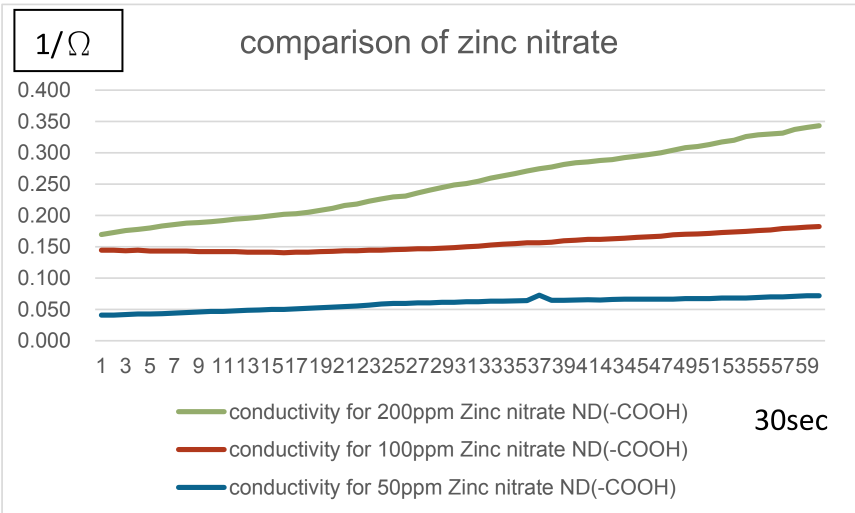
ND(-COOH) - 50ppm Zinc nitrate										
details/time(min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
resistance	24.592	24.552	24.062	23.604	23.583	23.140	22.711	22.282	21.879	21.476
:onductivity for 50ppm Zinc nitrate ND(-COOH	0.041	0.041	0.042	0.042	0.042	0.043	0.044	0.045	0.046	0.047
V	12.788	12.767	12.753	12.746	12.735	12.727	12.718	12.701	12.69	12.671
I	0.520	0.520	0.530	0.54	0.540	0.550	0.560	0.57	0.58	0.59
13.3-V for 50ppm Zinc nitrate ND(-COOH)	0.512	0.533	0.547	0.554	0.565	0.573	0.582	0.599	0.610	0.629

5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
21.456	21.083	20.707	20.350	20.002	19.990	19.661	19.340	19.024	18.713	18.400	18.117	17.592	17.085	16.842	16.839	16.604	16.600	16.370	16.367
0.047	0.047	0.048	0.049	0.050	0.050	0.051	0.052	0.053	0.053	0.054	0.055	0.057	0.059	0.059	0.059	0.060	0.060	0.061	0.061
12.659	12.65	12.631	12.617	12.601	12.594	12.583	12.571	12.556	12.538	12.512	12.501	12.49	12.472	12.463	12.461	12.453	12.45	12.441	12.439
0.59	0.6	0.61	0.62	0.63	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.71	0.73	0.74	0.74	0.75	0.75	0.76	0.76
0.641	0.650	0.669	0.683	0.699	0.706	0.717	0.729	0.744	0.762	0.788	0.799	0.810	0.828	0.837	0.839	0.847	0.850	0.859	0.861

15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
16.139	16.131	15.919	15.918	15.705	15.696	13.774	15.488	15.481	15.476	15.274	15.463	15.263	15.072	15.068	15.065	15.063	15.062	14.877	14.867
0.062	0.062	0.063	0.063	0.064	0.064	0.073	0.065	0.065	0.065	0.065	0.065	0.066	0.066	0.066	0.066	0.066	0.066	0.067	0.067
12.427	12.421	12.417	12.416	12.407	12.4	12.397	12.39	12.385	12.381	12.372	12.37	12.363	12.359	12.356	12.353	12.352	12.351	12.348	12.34
0.77	0.77	0.78	0.78	0.79	0.79	0.9	0.8	0.8	0.8	0.81	0.8	0.81	0.82	0.82	0.82	0.82	0.82	0.83	0.83
0.873	0.879	0.883	0.884	0.893	0.900	0.903	0.910	0.915	0.919	0.928	0.930	0.937	0.941	0.944	0.947	0.948	0.949	0.952	0.960

25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
14.857	14.675	14.667	14.662	14.484	14.301	14.286	14.115	13.942	13.930
0.067	0.068	0.068	0.068	0.069	0.070	0.070	0.071	0.072	0.072
12.331	12.327	12.32	12.316	12.311	12.299	12.286	12.28	12.269	12.258
0.83	0.84	0.84	0.84	0.85	0.86	0.86	0.87	0.88	0.88
0.969	0.973	0.980	0.984	0.989	1.001	1.014	1.020	1.031	1.042

【表 38】Zinc 50ppm with ND-COOH



【表 39】

Zinc with

ND-COOD

(4) 文字概述

觀察【表 31】、【表 35】與【表 39】可知奈米鑽石應有吸附趨勢，如【註 4】文獻中提及，該實驗可利用導電率波動曲線來分辨各種離子種類，而在奈米鑽石沉澱物上的清澈溶液經過導電率分析明顯發現平穩趨勢。由於酸洗後奈米鑽石上方仍含有 COOH 基，且在之後討論中本組的機制裡也有釋放離子的可能，且因 Ni(50ppm)導電率並不高，故能推測【表 35】(50ppm)導電度稍有上升趨勢原因。

(六) ND(酸洗後之奈米鑽石 ND-COOH)吸附不同重金屬之比較與錯離子吸附比較

1. 多種單一離子

(1) 研究數據

ionic/cc	origin	2.00	4.00	8.00	16.00	32.00
Cu	2403.66	1201.83	600.92	300.46	150.23	75.11
Co	3535.42	1767.71	883.86	441.93	220.96	110.48
Pb	1158.98	579.49	289.75	144.87	72.44	36.22
Fe	838.73	419.37	209.68	104.84	52.42	26.21
Ni	3097.11	1548.55	774.28	387.14	193.57	96.78

【表 40】ICP-MS 測出之原始溶液濃度(ppm)

註:

1. 2, …等數值表示稀釋倍率，而 origin 表配置的原樣本經 ICP-MS 檢驗並推算得知(原數據請見 3.原始數據)
2. 此數據未考慮到奈米鑽石所佔有體積(鑽石密度:3.52)，下面數據會先換算。

Copper	origin	after	differences
Cu	1400.81	1228.48	172.33
Cu	700.40	586.41	114.00
Cu	350.20	132.05	218.15
Cu	175.10	64.27	110.84
Cu	87.55	23.70	63.85

【表 41】Copper data

Cobalt	origin	after	differences
Co	2060.38	1098.74	961.64
Co	1030.19	699.71	330.48
Co	515.09	348.39	166.71
Co	257.55	152.39	105.16
Co	128.77	56.81	71.96

【表 42】Cobalt data

Lead	origin	after	differences
Pb	675.43	67.81	607.62
Pb	337.72	268.41	69.31
Pb	168.86	77.68	91.18
Pb	84.43	29.91	54.52
Pb	42.21	16.85	25.37

【表 43】Lead data

Iron	origin	after	differences
Fe	488.80	316.95	171.85
Fe	244.40	156.53	87.87
Fe	122.20	54.02	68.18
Fe	61.10	20.92	40.18
Fe	30.55	2.67	40.18

【表 44】Iron data

Nickel	origin	after	differences
Ni	1804.94	1548.57	256.36
Ni	902.47	818.39	84.08
Ni	451.23	90.26	360.97
Ni	225.62	118.52	107.10
Ni	112.81	31.99	80.82

【表 45】Nickel data

ion/dilute	2.00	4.00	8.00	16.00	32.00
Cu	172.33	114.00	218.15	110.84	63.85
Co	961.64	330.48	166.71	105.16	71.96
Pb	607.62	69.31	91.18	54.52	25.37
Fe	171.85	87.87	68.18	40.18	27.88
Ni	256.36	84.08	360.97	107.10	80.82

【表 46】各溶液吸附濃度差異之比較值

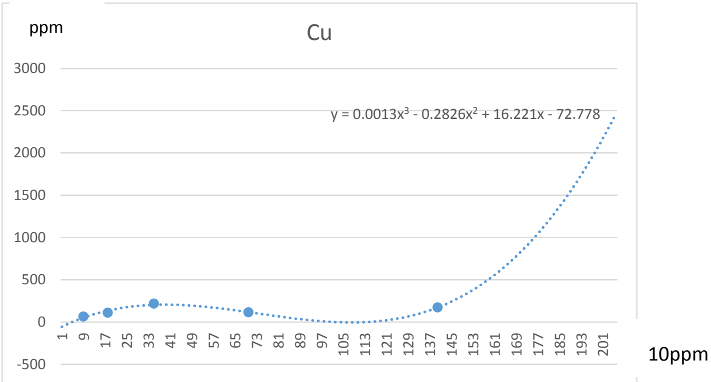
(2) 研究數據整理

A. 綜合整理

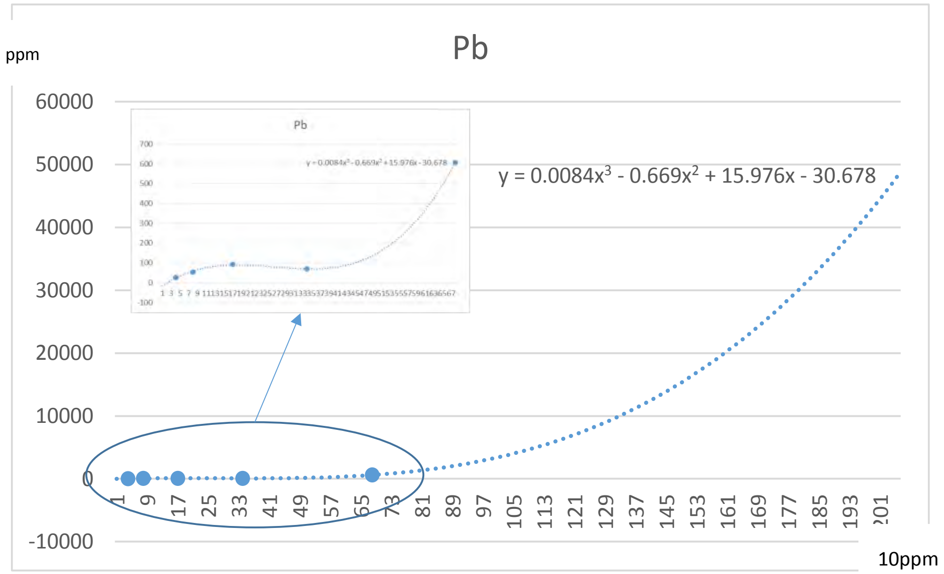
在此表中明顯探討出各曲線差異:分為兩種:

a. Co,Fe 有類似於依數性質(濃度增加吸附率增加)之特性

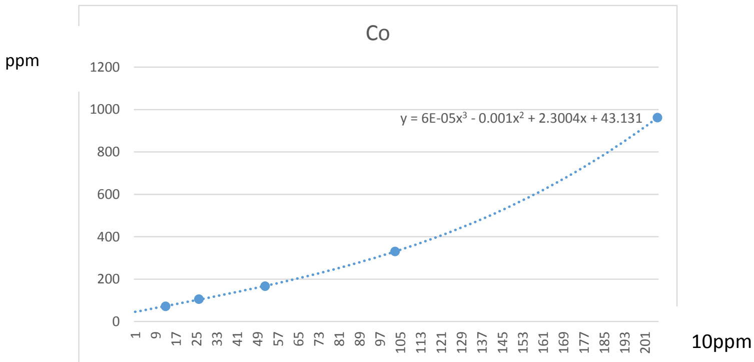
b. 先上升下降又上升的特質(Cu Pb Ni)



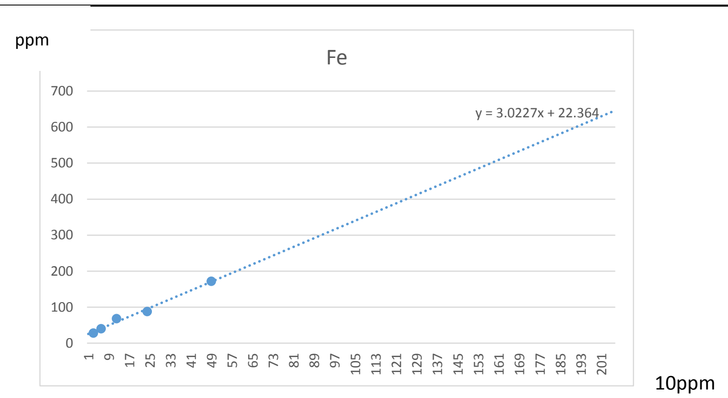
【表 47】硝酸銅吸附濃度比較與趨勢線



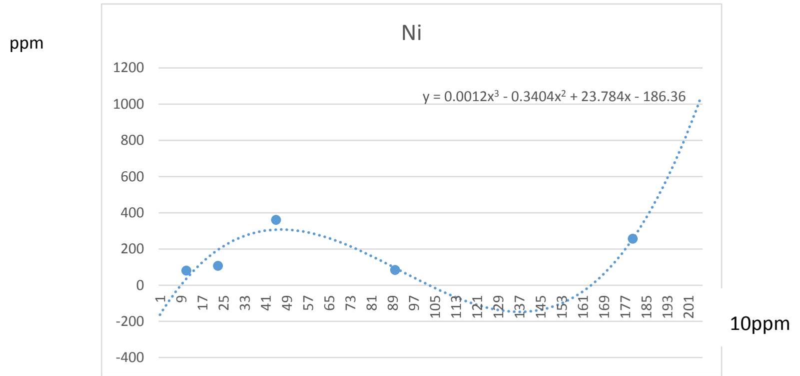
【表 48】硝酸鉛吸附濃度比較與趨勢線



【表 49】硝酸鈷吸附濃度比較與趨勢線



【表 50】硝酸鐵吸附濃度比較與趨勢線



【表 51】硝酸鎳吸附濃度比較與趨勢線

B. 個別離子分析曲線圖【吸附前後差/最終吸附濃度】

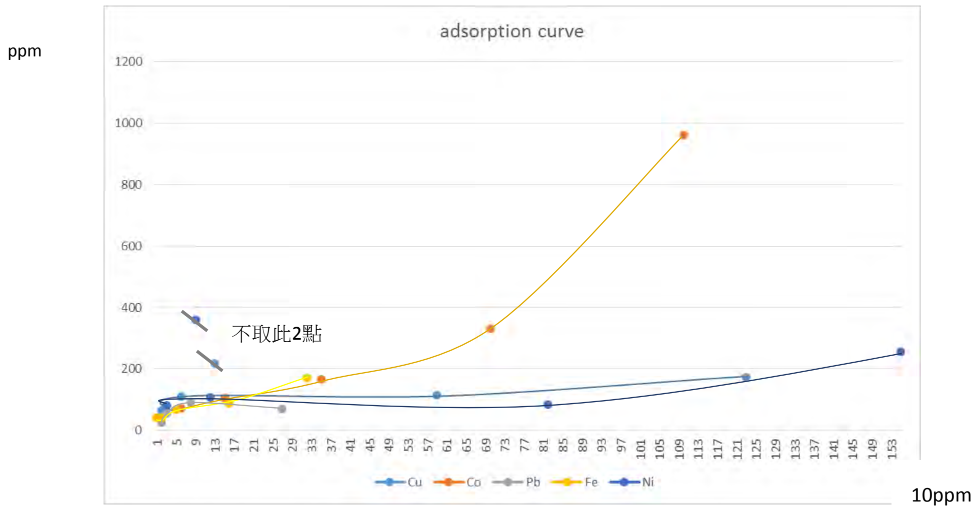
在以下表格為吸附曲線

低與高即為濃度小到大的排列方式。

此次圖表所顯示為【吸附前後濃度差/最終濃度】

從表中了解鈷有最大的吸附率。

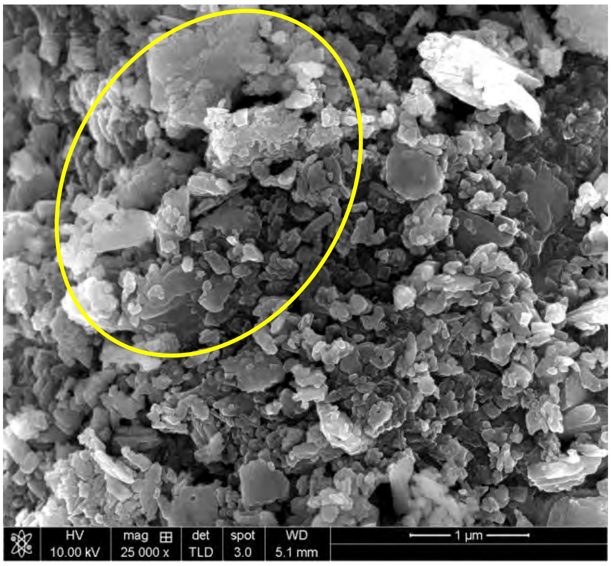
其他吸附粒子的情形因時間有限尚無機會作多次研究，將於報告繳交後將做更多實驗以確認實驗正確性



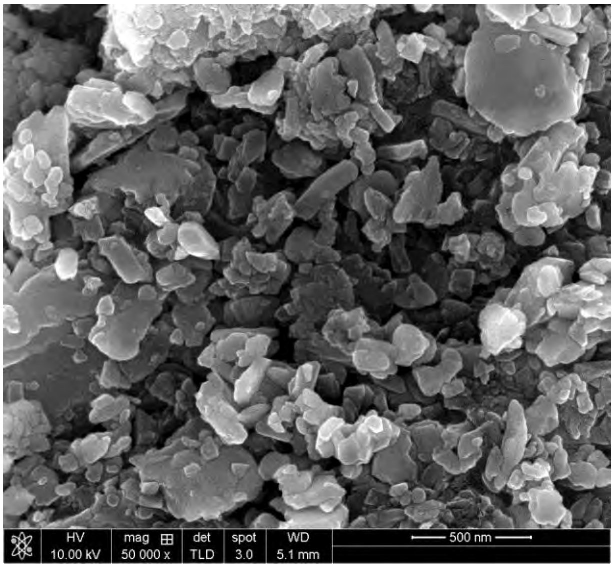
【表 52】吸附曲線比較

2. 單一離子(Cu,Co,and Fe)於 SEM 下微觀

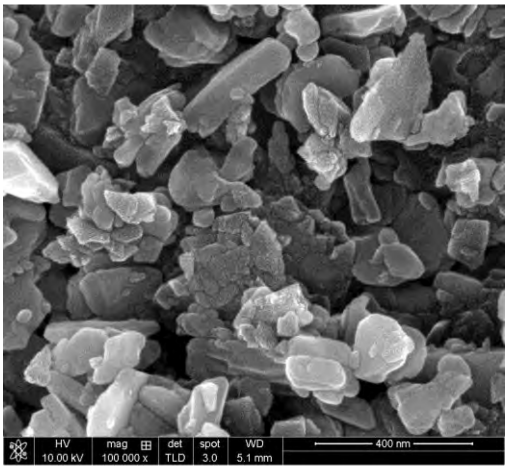
(1) 硝酸銅 $Cu(NO_3)_2$



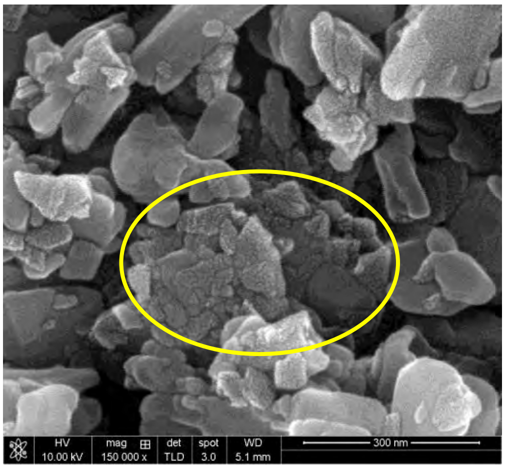
【圖 58】$Cu(NO_3)_2$ ND under SEM(25000*)



【圖 59】$Cu(NO_3)_2$ ND under SEM(50000*)



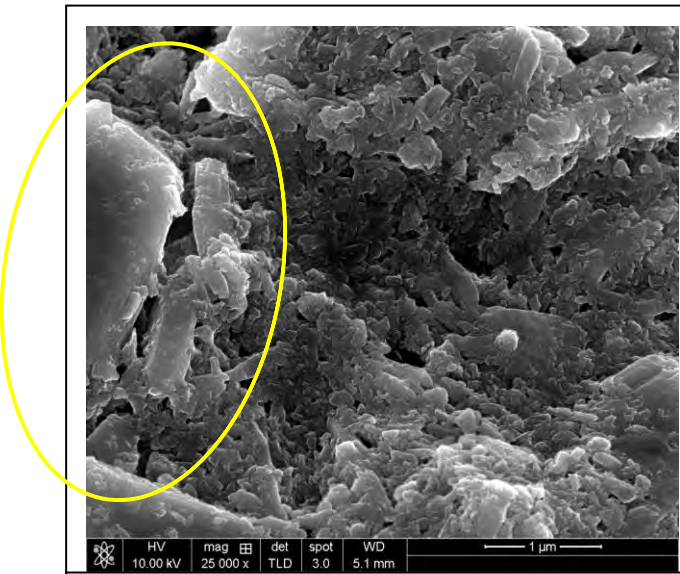
【圖 60】$Cu(NO_3)_2$ ND under SEM(100000*)



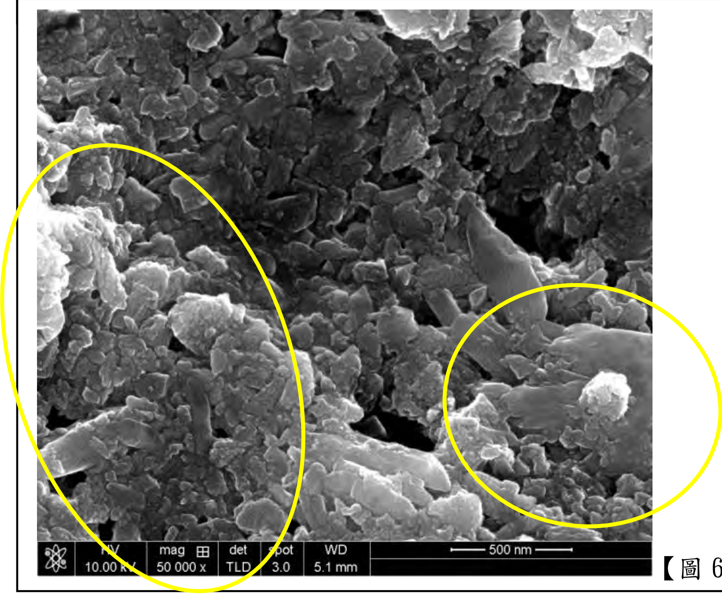
【圖 61】$Cu(NO_3)_2$ ND under SEM(150000*)

在上圖中，以黃色圓圈圈出區域可看到很多奈米鑽石沉積。

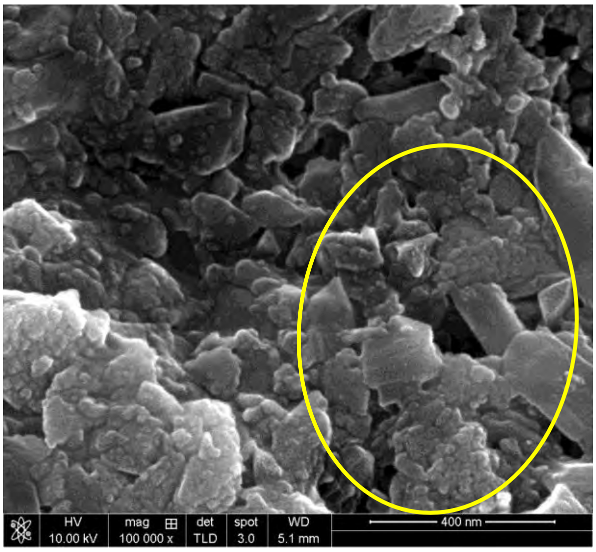
(2) 硝酸鈷 $Co(NO_3)_2$



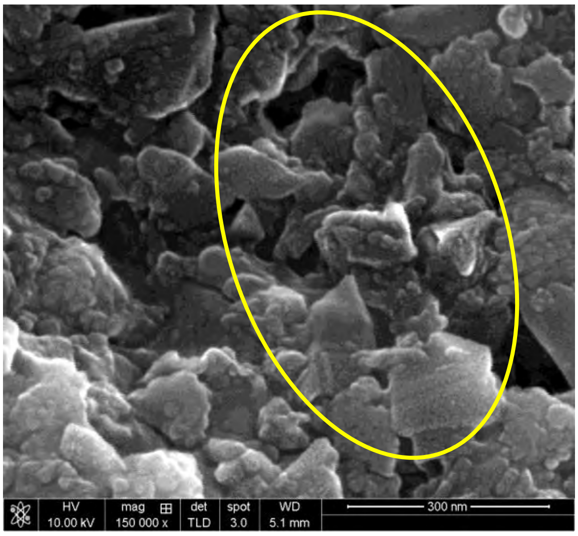
【圖 62】$Co(NO_3)_2$ ND under SEM(25000*)



【圖 63】$Co(NO_3)_2$ ND under SEM(50000*)



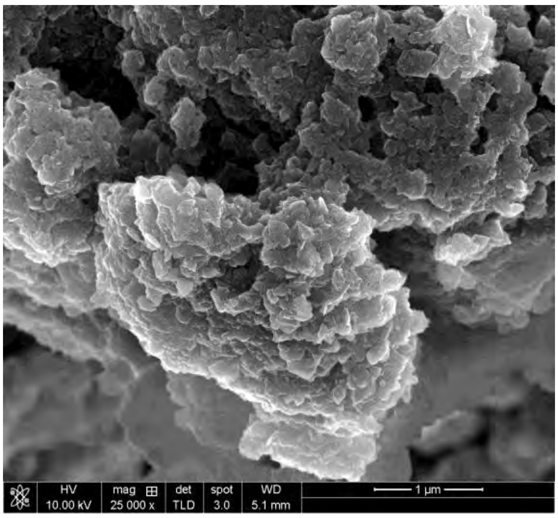
【圖 64】$Co(NO_3)_2$ ND under SEM(100000*)



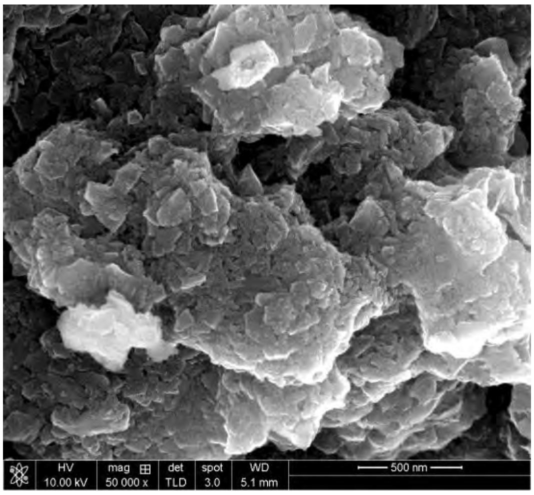
【圖 65】$Co(NO_3)_2$ ND under SEM(150000*)

在黃色圓圈處是硝酸鈷吸附後的小型沉澱

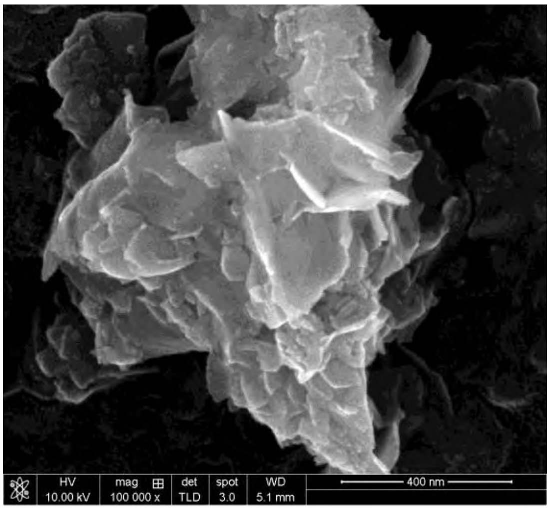
(3) 硝酸鐵 $Fe(NO_3)_3$



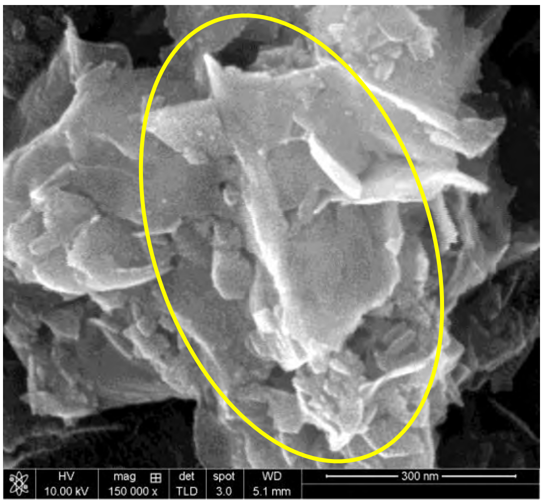
【圖 66】$Fe(NO_3)_3$ ND under SEM(25000*)



【圖 67】$Fe(NO_3)_3$ ND under SEM(50000*)



【圖 68】$Fe(NO_3)_3$ ND under SEM(100000*)

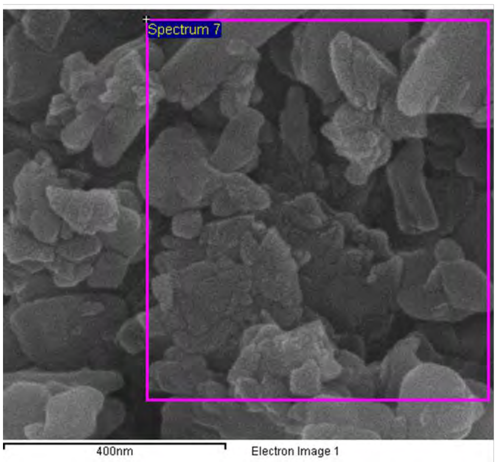


【圖 69】$Fe(NO_3)_3$ ND under SEM(150000*)

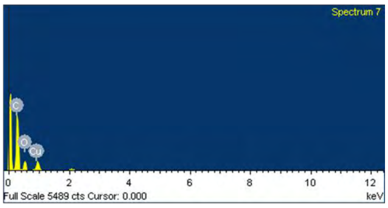
看似平面的立體沉澱事實上仍由奈米鑽石小顆粒聚集而成，如上圖圓圈所指出。

3.　單一離子元素分析

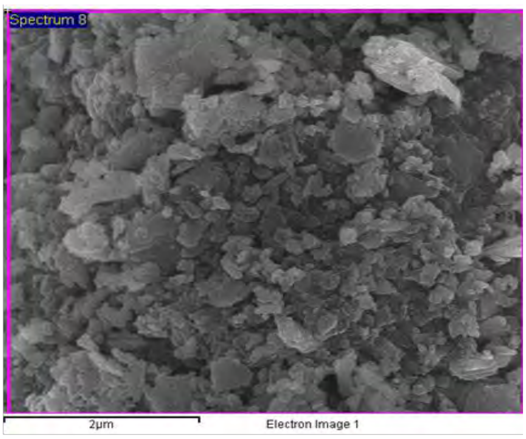
(1)　硝酸銅



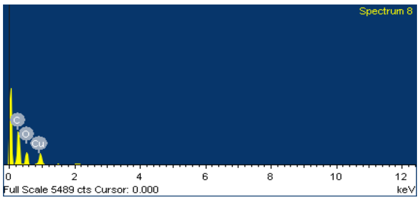
Element	Weight%	Atomic%
C K	68.30	81.61
O K	16.73	15.01
Cu L	14.97	3.38
Totals	100.00	



【表 53】$Cu(NO_3)_2$ ND under SEM(400nm)



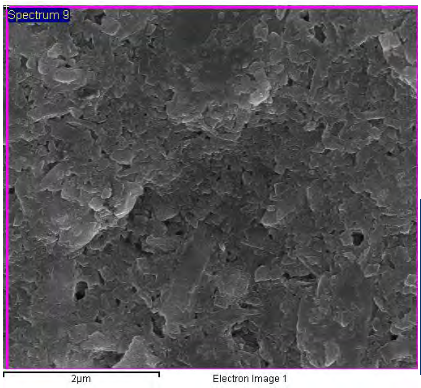
Element	Weight%	Atomic%
C K	54.55	71.42
O K	23.56	23.16
Cu L	21.89	5.42
Totals	100.00	



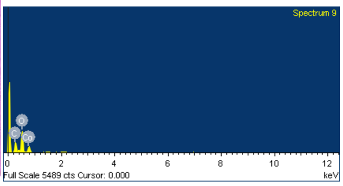
【表 54】$Cu(NO_3)_2$ ND under SEM(2μm)

從上面 2 張分析可得總體而言氧佔的比例相對較高

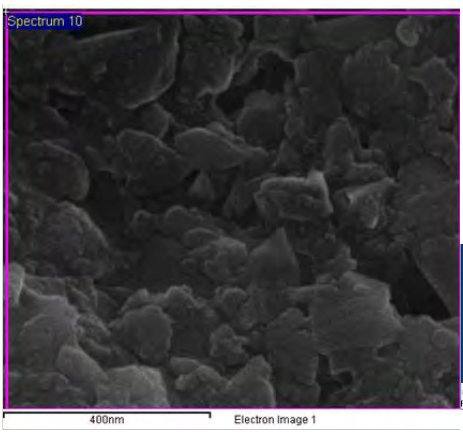
(2)　硝酸鈷



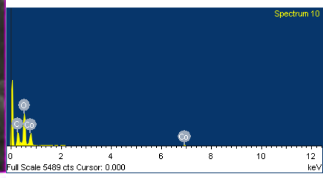
Element	Weight%	Atomic%
C K	25.25	41.48
O K	37.28	45.98
Co L	37.47	12.54
Totals	100.00	



【表 55】$Co(NO_3)_2$ ND under SEM(2μm)



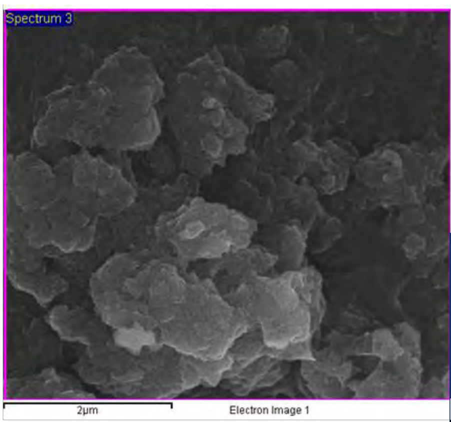
Element	Weight%	Atomic%
C K	22.35	39.27
O K	34.26	45.19
Co L	43.39	15.54
Totals	100.00	



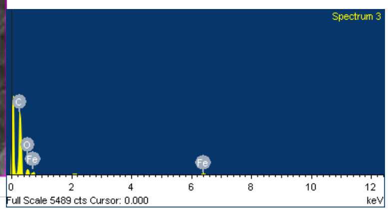
【表 56】$Co(NO_3)_2$ ND under SEM(400nm)

氧的比例佔極高且鈷的比例與碳的比例相當。(Mapping 疊圖可看討論)

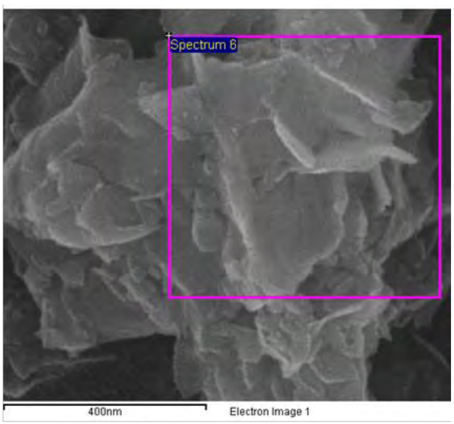
(3) 硝酸鐵



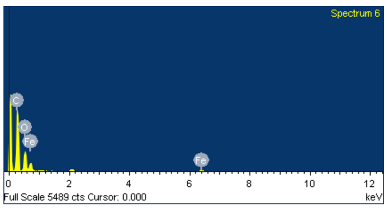
Element	Weight%	Atomic%
C K	74.54	83.17
O K	17.93	15.02
Fe K	7.53	1.81
Totals	100.00	



【表 57】$Fe(NO_3)_3$ ND under SEM(2μm)



Element	Weight%	Atomic%
C K	52.34	71.70
O K	19.43	19.98
Fe L	28.24	8.32
Totals	100.00	



【表 58】$Fe(NO_3)_3$ ND under SEM(400nm)

皆可測得鐵元素且比例相當

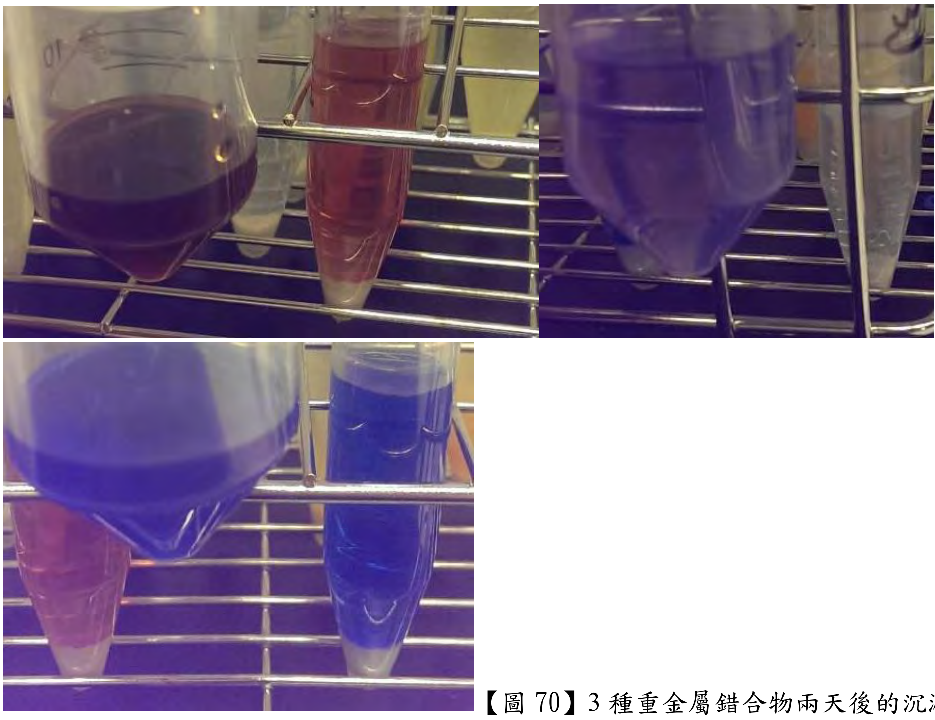
4. 錯離子化合物吸附情形

在此三種錯離子化合物內以銅氨錯離子吸附效率最為顯著、鎳離子吸附效率亦達高點，鈷氨錯離子吸附效率也不差，可知其不影響奈米鑽石的吸附功能，更凸顯出專一性的吸附方式。

complex	origina	after
Cu(NH3)x	1203.56	288.84
Co(NH3)6	106.58	92.17
Ni(NH3)6	256.15	154.97

【表 59】各溶液吸附濃度差異之比較值

在圖中三種皆有變較淺色的情況，故推測可能為或是本身物質差異。



【圖 70】3 種重金屬錯合物兩天後的沉澱情形

(七) 重複利用討論

本組透過硝酸沖洗並利用 ICP-MS 確認吸附有釋放情形。

release	conc'
Pb	601.23
Ni	2012.43

【表 60】釋放數值

(八) 討論

1. 對於 LM324 系統改變之原因與相關實驗

(1)對於【註 3】文獻方式之相關實驗

A. 先前推測與實驗目的

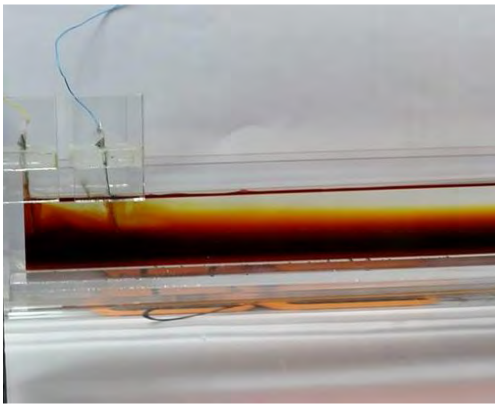
於過去的實驗中【註 3】，本組提出大烏雲理論，意指溶液導電度(電阻)變化原因是從壓克力箱注入端以一堆似雲離子團的方式推移至負極。在這個假設下仍有一個問題:為何溶液電阻曲線(當時並不用倒數取導電度)會呈現不規則的震盪趨勢(上上下下重複)，如上面圖表中重金屬水溶液導電度所示。雖然這些不規則曲線為一種判斷金屬離子的方式，且亦發現濃度並不影響曲線的形狀。賽後，本組仍對此現象進行討論，並了解原因。

B. 實驗方法

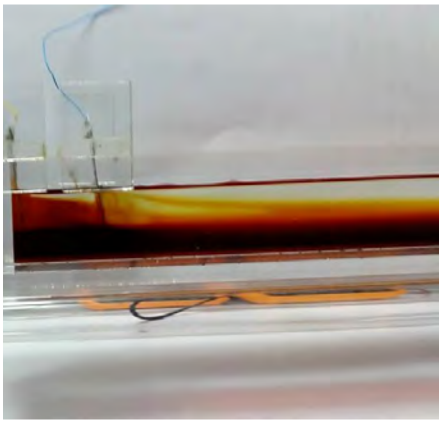
相同於【註 3】中的實驗，利用一個大型(長 20 公分)的壓克力箱裝滿水，但改變距離，直接於邊處放置白金片組，並接上 LM324 實驗裝置。靜置 5 分鐘使其波浪平穩再加入有顏色的溶液，分別為碘酒(多、中、少)與飽和硝酸銅溶液，觀察注射後與受電場下的影響。

C. 實驗結果

a. 碘(濃度高)之電解現象相關實驗

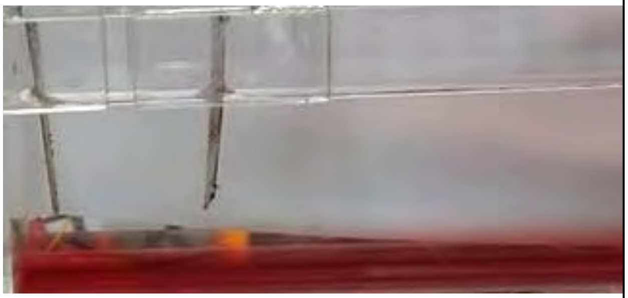


【圖 71】放入濃碘酒(12min)

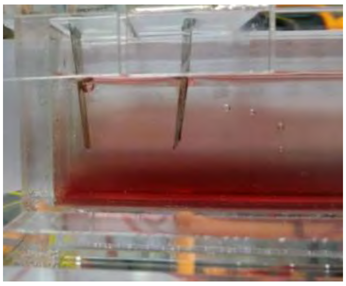


【圖 72】放入濃碘酒(1hour)

b. 碘(濃度中)之電解現象相關實驗



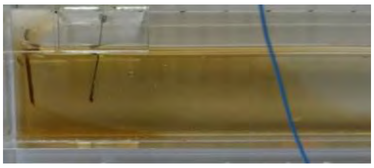
【圖 73】放入不少碘酒(instant)



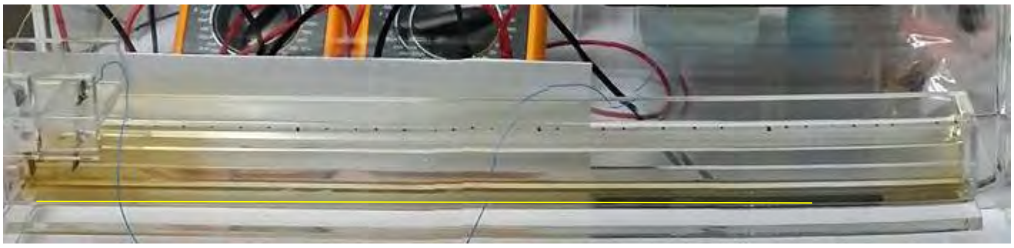
【圖 74】放入不少碘酒(20min)

c. 碘(濃度少)之電解現象相關實驗

【圖 75】放入少碘酒(3hours)



【圖 76】細部觀察(3 hours)

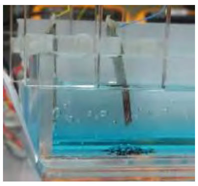


【圖 77】放入少碘酒(50min)

d. 硝酸銅之電解現象實驗

【圖 78】放入硝酸銅(黃色曲線為分水與硝酸銅溶液的曲線)

【圖 79】放入硝酸銅



【圖 80】細部觀察(oxidation-reduction reaction)

(2)文字敘述

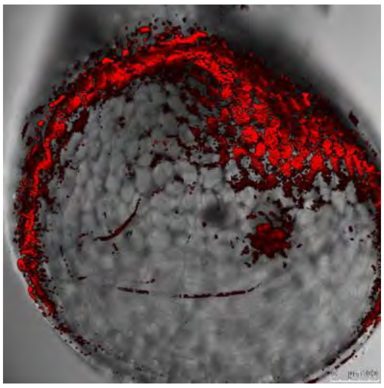
如圖上圖所示，此些皆有一項特點，即是分割面清楚，足以用來證明其並不以大烏雲理論運作，對於其運作方式則可藉由不同時間圖解釋，從上圖的時間變化亦可得知界面逐漸模糊、並有明顯聚集情形，從碘的實驗中最為顯著。而是後，本組亦得到良好解釋，亦即該溶液被吸起與產生之相關電化學反應實為影響電導度之主要原因。

(3)研究改良

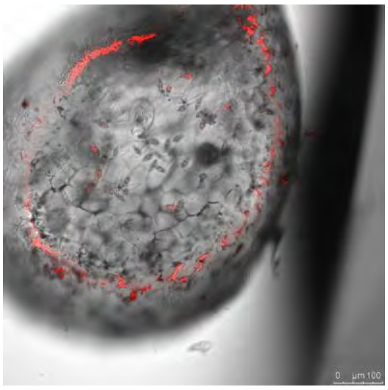
因本實驗顯示並不需要相當大之容器，主要為其中電化學反應之相關影響，故本組決定以溶液直接加入的方式並以其所造成的電阻變化作分析與結果論述。

2. 對於奈米鑽石與捕蟲囊表面覆蓋情形之討論與見解

在【圖 34】、【圖 35】可發現奈米鑽石的強烈吸附性，並得以推估其對其他物質的吸附探討。



【圖 34】bladder traps' reflection in 5μg/ml's ND solution.

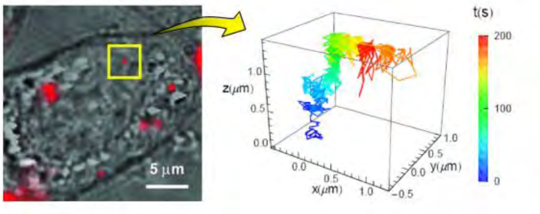


【圖 35】bladder traps' reflection in 100μg/ml's ND solution.

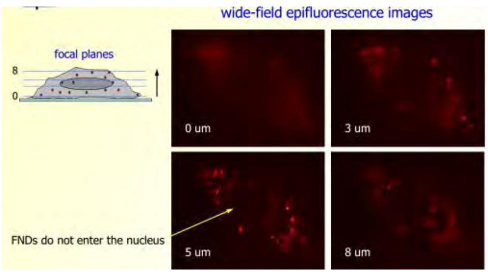
3. 奈米鑽石生物共生性探討

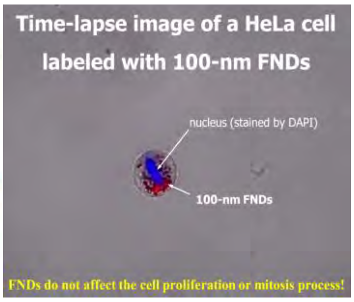
(1)文獻探討

在奈米鑽石的應用方面已有許多生物方面探討，如【表 61】所示。而應用方面多以其生物共生性為主，在一篇論文亦對其在生物體內的 3D 移動情形探討，確定其絕不會進入細胞核，且目前已有實驗研究證明奈米鑽石並不會對微生物的生長造成影響。可反駁【註 5】的毒性假說。

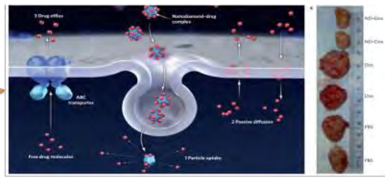


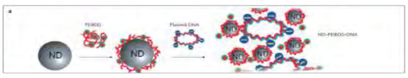
【表 61】nuclear statement【註 2】

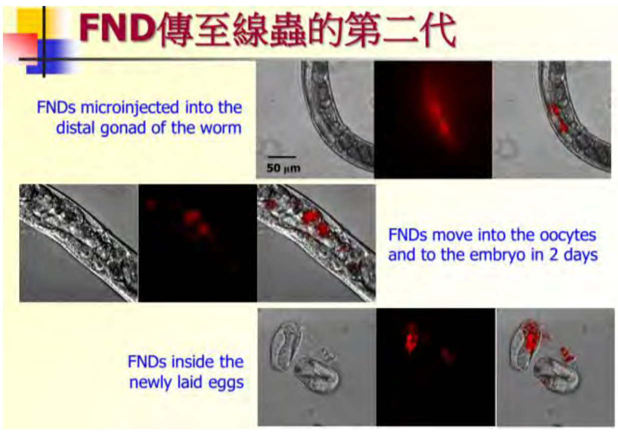




1. Tissue scaffolds and surgical implants
2. Drug delivery
3. Different Absorption
(1) DNA Absorption
(2) Drug and other things attachment
4. Mouse vein tracing and reflection.







【表 62】applications【註 1、註 2】

(2)實驗證明

適當的奈米鑽石並不會造成任意傷害甚有增加其活躍性情形，但若突然施以太多鑽石當然尚會對環境造成影響。所幸與本組實驗中探討出少數奈米鑽石即有強力吸附功效之事，增加奈米鑽石吸附方面之實用性。見【圖 35】

4. 對於結果(二)、結果(三)與結果(四)無法看出規則性甚有導電率上升趨勢之解釋與探討。

如【討論一】提及，本實驗之變素及原因即由該溶液內梨子濃度、種類所致，各能表現其專一性質，如所有表格之繪圖，若該溶液內尚有離子，則曲線差異不大，若該溶液內有其餘離子存在，則將會影響數據顯示。本導電率變化測量方法，已在實驗中證明個溶液內的離子變化，亦即此為一簡單測量分析方式，若該水質內有離子變化將影響本組裝製數據曲線，屆時即可再透過更精密的儀器進行內容物分析。

5. 硝酸鐵特殊情形

當奈米鑽石加入硝酸鐵溶液時會出現如右列的分離情形，經查詢得知其密度最小，故不是因密度影響。本組懷疑其已達飽和，並且不在與下面溶液反應(奈米鑽石溶液成黃色)。【圖 81】

【圖 81】iron nitrate

【圖 82】從此圖可知以作用的奈米鑽石呈現黃色即為氧化後吸附於奈米鑽石上的顏色顯現。

6. 氧化金屬吸附

從上頁得知氧化鐵的吸附，本組可再從 SEM 元素分析得各硝酸金屬化合物表格並透過疊圖分析金屬原子與氧原子分布情形，如下圖所示。由此可確定氧化金屬存在。

在外觀上即有顯著改變者有

(1) 硝酸鐵:在離心後奈米鑽石皆產生黃色沉澱，表其吸附有氧化物。【圖 83】且在樣本製作上也可見強烈顯色效應。

(2) 硝酸銅、鈷:樣本製作後可看見外圍顏色【圖 84】-【圖 85】

【圖 83】$Fe(NO_3)_3$樣本明顯可見外圍與內部的褐色顯色

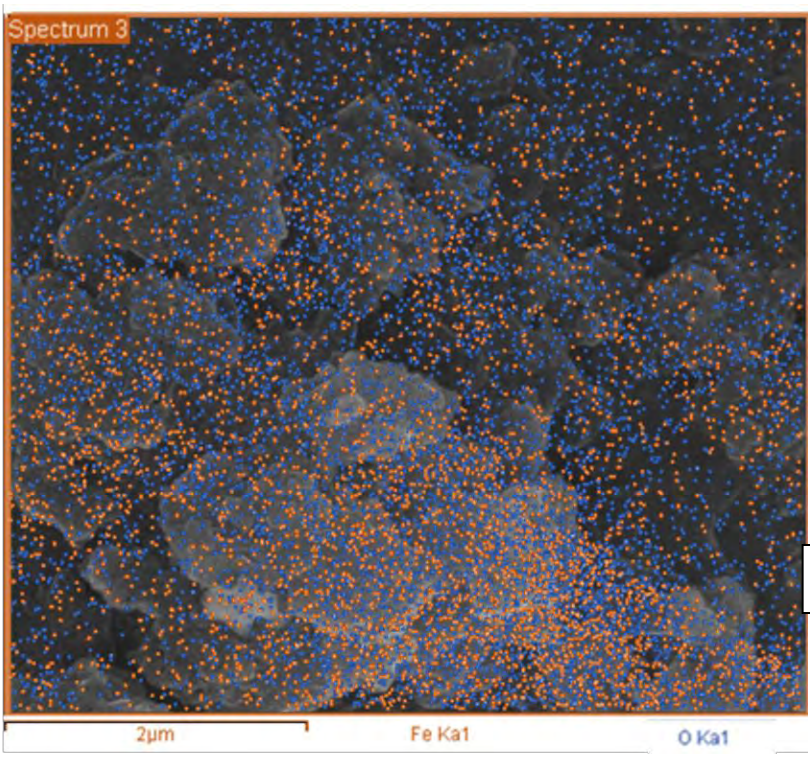
【圖 84】$Cu(NO_3)_1$樣本明顯可見外圍與內部的藍色顯色

【圖 85】$Co(NO_3)_1$樣本明顯可見外圍的紫黑色顯色

疊圖分析

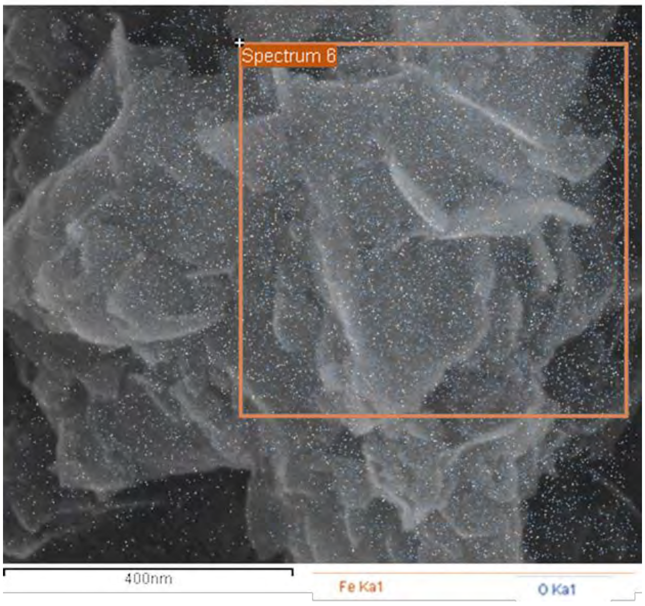
(1)由下圖可得 $Fe(NO_3)_2$、$Cu(NO_3)_2$和 $Co(NO_3)_2$疊圖分析結果，其中可明顯得知在乾燥樣本中氧與金屬確實有產生化合，且此亦可以成為本組吸附機裡的一大證據(離子交換)。

(2)硝酸鈷樣本含氧的比例極高竟然大於奈米鑽石的碳比例，亦即氧應完全吸附在奈米鑽石表面此亦可從自製疊圖得知。

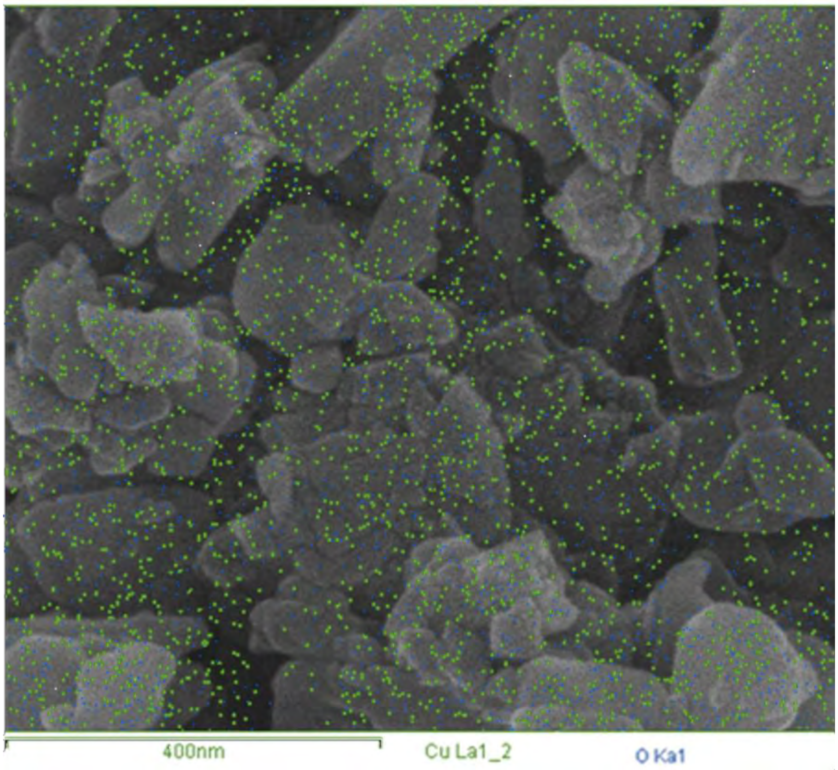


FeO 與 Fe_2O_3

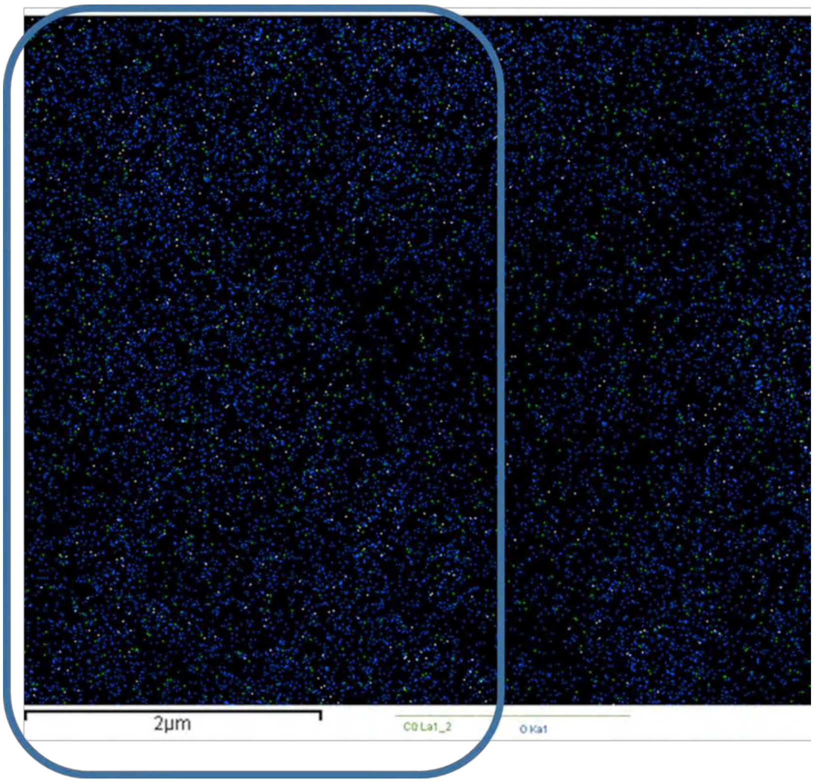
【圖 86】鐵與氧疊圖分析-1(2μm)



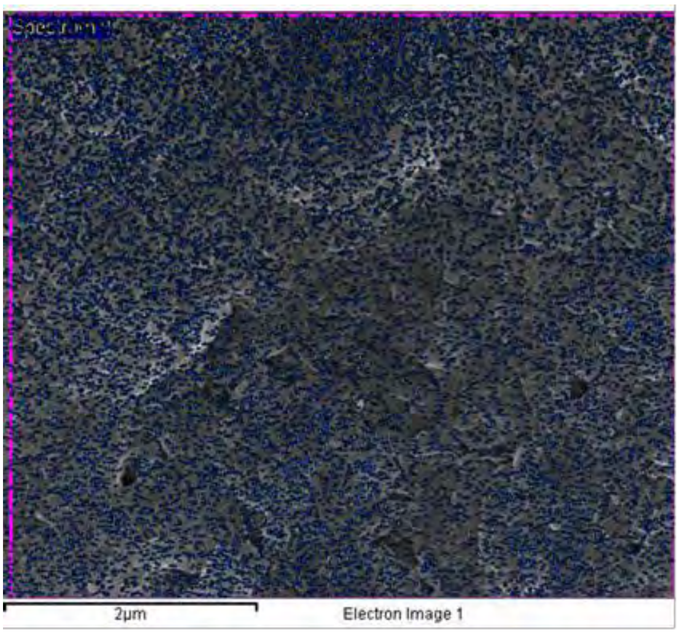
【圖 87】鐵與氧疊圖分析-1(400nm)



【圖 88】銅與氧疊圖分析-1(400nm)

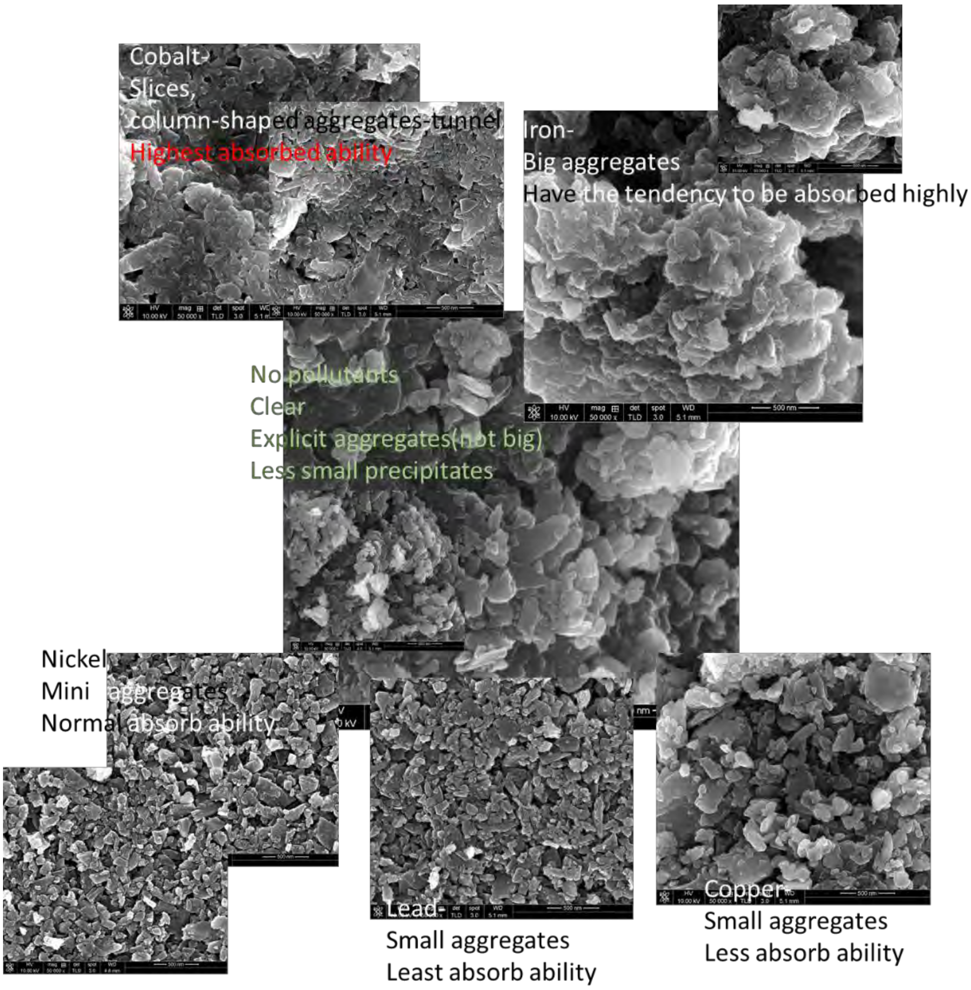


【圖 89】鈷與氧疊圖分析-1(2μm)

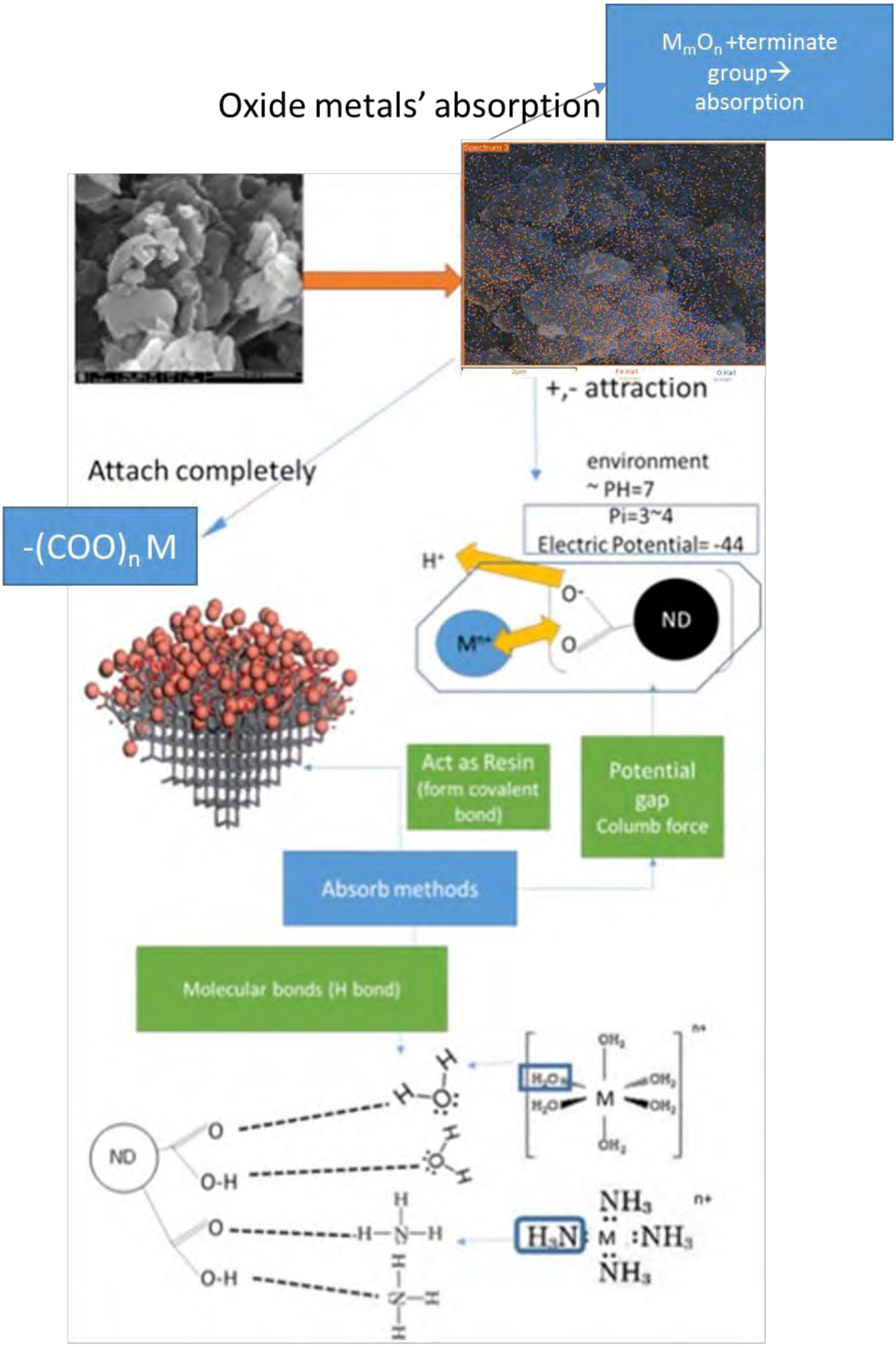


【圖 90】原圖(鑽石)與氧在硝酸鈷的沉澱-2(2μm)

7. 奈米鑽石比較(50000*整理，無重金屬與單一離子)

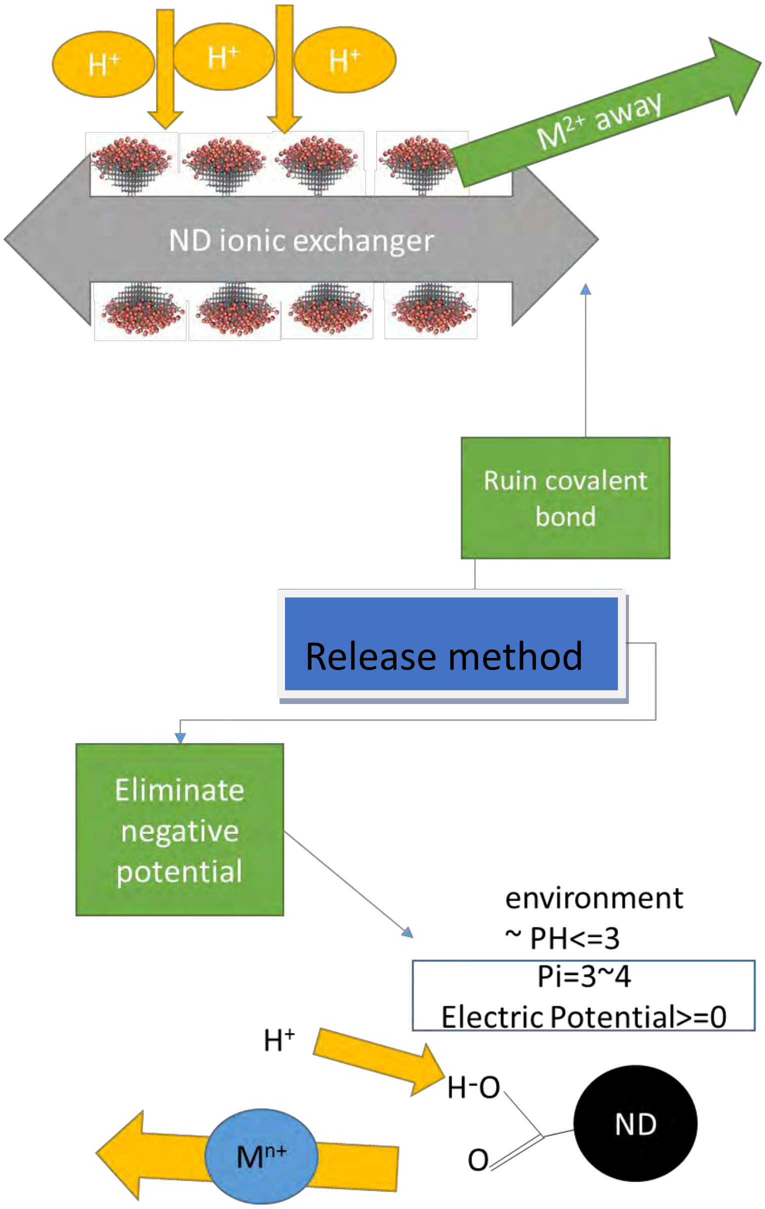


8. 奈米鑽石吸附機理



Oxide metals' absorption
MmOn +terminate group→ absorption
+,- attraction
environment
~ PH=7
Pi=3~4
Electric Potential= -44
Attach completely
-(COO)n M
H+
O-
O
ND
Act as Resin (form covalent bond)
Potential gap Columb force
Absorb methods
Molecular bonds (H bond)
ND
O
O-H
O
O-H
NH3
M
:NH3
NH3
H3N

9. 奈米鑽石釋放機理


H+
H+
H+
M2+ away
ND ionic exchanger
Ruin covalent bond
Release method
Eliminate negative potential
environment
~ PH<=3
Pi=3~4
Electric Potential>=0
H+
H-O
O
ND
Mn+

四、結論與應用

(一) 奈米鑽石吸附性質整理

1. 重金屬離子吸附

(1)離子種類專一性

在研究結果中本組從最簡易之檢驗法~LM324 導電率測試至 ICP-MS 準確濃度皆可歸納出上述之吸附與導電曲線對各種離子的專一性。

A. 導電率曲線專一性

本次實驗所運用之導電度測量方法確立對各種溶液成分之專一性，故在本次實驗所運用之簡易測試方法可為一檢驗吸附性質之簡易設備。

B. 吸附曲線專一性

在本組所繪製的吸附曲線中，對每種離子的吸附特性皆可繪製出不同曲線分布，並如一般的吸附曲線相似，但本組也發現有些點有特別高的趨勢，此次繪製圖裡並無將那些點納入，然而本組也會在之後的時間中重複實驗以確保實驗的準確性質。

(2)重複利用性

在本次實驗中所測得之奈米鑽石釋放離子濃度約 800-2012 ppm 左右，意指奈米鑽石上所吸附之重金屬離子可被洗出。故其重複利用性可以確定。

(3)錯離子化合物之吸附

在多篇文獻中，本組皆發現許多吸附器並無吸附錯離子化合物之功能，然而本組數據顯示奈米鑽石極具錯合物吸附特性，更增添奈米鑽石於現實吸附上之應用。

2. 巨觀、微觀觀察

(1)巨觀觀察

本組能找到此方向之原因為加入重金屬溶液後，懸浮液內的奈米鑽石有沉澱現象。後經實驗也證明奈米鑽石溶液可使金屬氧化並吸附氧化物，而此亦可應用在定性分析之檢驗。

(2)微觀觀察

在 SEM 下的奈米鑽石有不同的外觀與聚集情形，故已證明其有吸附特性，且各種離子會有不同的聚集性質。

3. 吸附假說(可參閱【討論 8】)

(1)氧化吸附假說

本組在實驗過程內可了解到氧的比例會因不同的離子種類而改變本組在【討論 6.】裡特對此事發表見解與看法，並相信其是間接吸附的重要元素。

(2)酸根置換假說

在【討論 7.】內可了解到外觀差異也可以做為吸附依據，此時可先觀察到有氧處不一定有重金屬，但有重金屬處常看見氧，由氧與重金屬的堆疊圖【圖 86】~【圖 90】可得知氧與重金屬的相對位置與數目，更能確定此假說之可能性。

(3)正、負電靜電吸引

本組由奈米鑽石在一般狀態下介面電位為負的特性推測此假說。

而奈米鑽石粒徑與方向也會影響一物(在此表離子)沉澱形狀與結構。

4. 生物性質應用

(1)生物共生性

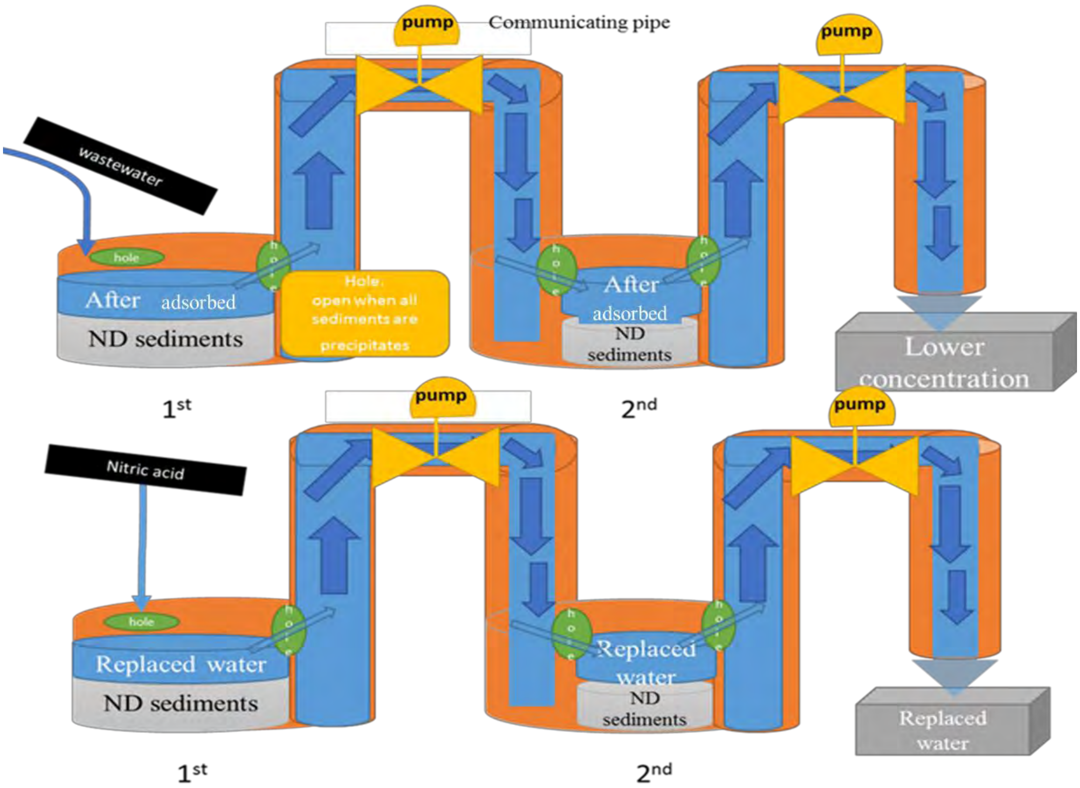
在最初黃花狸藻實驗中，本組可清楚點出黃花狸藻並不會受奈米鑽石影響而失去其生存功能，甚至有許多共生微藻活動力反而更加旺盛，由此得知其有生物共生性質。

(2)對植物體的附著

在前面提及的照片中可清楚看出奈米鑽石在捕蟲囊上的吸附特性(一層)。然而其對為藻類、微生物類並不會造成影響，可想見，捕蟲囊或表皮細胞上應有特殊官能基讓其進行吸附即聚集。

(二) 應用

1. 本組繪製工程應用概念圖(左而右之設計)

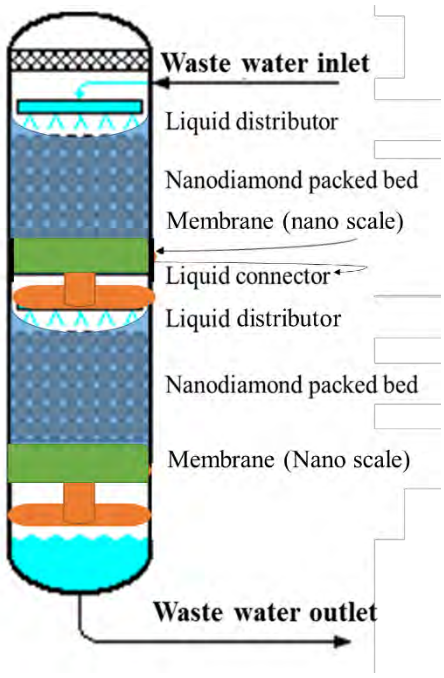


在一工廠內設為兩管線，一為廢水入口二為恢復入口。

第一部分:當廢水進入時，靜置並等到奈米鑽石沉澱，透過連通管原理水會不段循環，共分為二次吸附，最後出來的水將為含有重金屬離子低濃度之廢水。

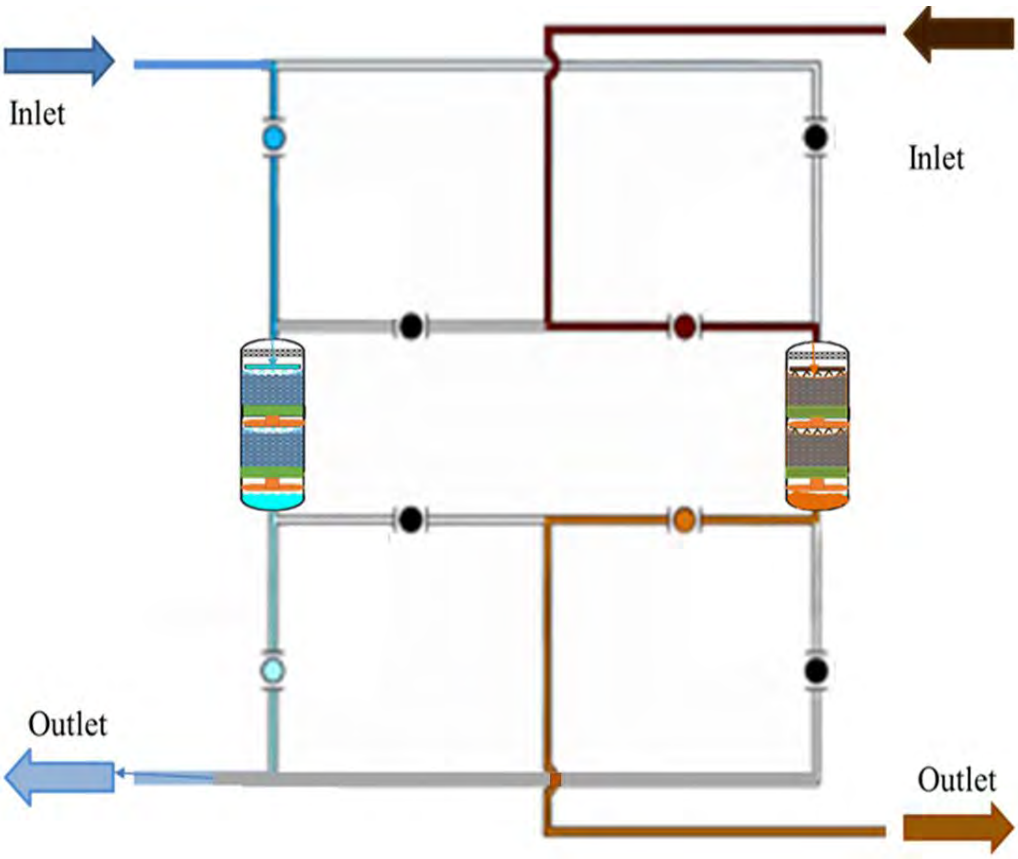
第二部分:加入酸性物質(可來自工業廢水等)使整體 PH 值降低而釋放重金屬離子(可見討論 8.)。

2. 本組繪製工程應用概念圖(吸附塔設計)



本設計透過薄膜過濾並過濾出最清潔之水溶液，如同常見吸附管，可交換吸附管來達到重複利用與吸附效果。

總設計圖 – Adsorption and Regeneration Cycle



五、參考文獻

1. 李嘉祐、鄭楚玄。2010 年。應用吸水高分子螯合重金屬離子及奈米銀的製備。2010 年臺灣國際科學展覽會優勝作品專輯。
2. 莊淳喬、莊迪喬。2006年。水生開花食蟲植物絲葉狸藻捕蟲囊構造及共質體運輸。台灣2006年國際科展展覽會研究報告書。
3. 夏志豪、黃厚宜。2014年。利用L.M.S即時顯示系統建立資料庫，在重金屬汙染監測上之應用。2014年台灣國際科學展覽會研究報告書。
4. 張煥正研究員。居禮夫人的寶石:螢光奈米鑽石。研究報告。
5. 黃品慈、陳昕。2010年。奈米粒子對細胞與生物之毒性及其分布。2010年臺灣國際科學展覽會優勝作品專輯。
6. Vadym N. Mochalin, Olga Shenderova, Dean Hoand, Yury Gogotsi. DECEMBER 2011. The properties and applications of nanodiamonds. Nano Technology Review Article. NNANO.2011.209. p.11~p.20.

全文完

Author: Chih-Hau Shiah

ISEF 2015 Science Project Report

Abstract

With the growing concern over environmental issues and the rapid development of nanomaterials, a more efficient adsorbent for heavy metal removal is crucial. In our research, we used Nanodiamond (ND) made by High Temperature High Pressure (HTHP) process, and ran through acidified procedure to enhance NDs' carboxylic acid groups (-COOH) ratio, making Acidified Nanodiamonds (ANDs). ANDs was used as an adsorbent of heavy metals. The mechanisms and characteristics in the adsorption reaction were examined. The materials were characterized by several techniques, including IR spectroscopy, Scanning Electron Microscopy (SEM), Zetasizer, ICP-MS, confocal microscopy etc. For the purpose of being an environmental friendly adsorbent, biocompatibility is a crucial factor. We found that ND was not harmful to the creatures in aquatic environment, a fact verifiable when we added ND(aq) to algae, *Ultracularia gibba*. In term of the heavy metal removal, our results show that the adsorption capacity is varied with different metal ions, and special adsorption reasons are illustrated. In addition, the effect of the ND's concentration, pH and time of adsorption were all studied in our research. Reusability is another important factor to become a novel green adsorbent. ANDs is found to be reusable after adding nitric acid to the NDs precipitates. All these are consistent with the key elements of the Twelve Principles of Green Chemistry, which concerned Prevention,

Atom Economy, Designing Safer Chemicals, and Renewable Feedstock.

Acknowledgement

First of all, I wish to express the deepest appreciation to my advisor, Professor. Soofin Cheng at Department of Chemistry, National Taiwan University, for her guidance and patience to assist me for completing this enormous project. I also gratefully thank to Profesor Ya Hsuan Liou at the Department of Geoscience, National Taiwan University for borrowing me countless apparatus and giving me lots of encouragements; Dr. Chia-Yi Fang at Institute of Atomic and Molecular Science, Sinica, for supporting me materials to research and leading me into the Nanodiamonds field; Professor Guor-Rong Her at the Department of Chemistry, National Taiwan University, for giving me numerous advices on my presentation and logical thinkings; Professor Chao-Sung Lin at Department of Material Science, National Taiwan University, for borrowing me special apparatus; Ms. Tanya Tan at Taipei Municipal Jianguo Senior High, the best teacher I met, for your encouragements and advices to make me a real scientist; Senior Mao, Pin-Hau Huang, and Ren-Wei Chang for helping me fit in the lovely laboratorie and leading me to use SEM, spectroscopies (IR and UV-Vis), and ICP-MS respectively; all seniors in laboratory, for treating me as one of your members.

Finally, I would like to thank for all my classmates, teachers, and, most importantly, my parents, for encouraging and supporting me. This is the first project I contact with universities and laboratories by myself for fulfilling my dream. Thanks for everyone whom helped me and of course my old partner, Jerry Huang for your consideration; best listener, Andy Wang, for always comforting me when I am under pressure. Good luck~ Thanks!

I. Introduction

A. Motivation

Heavy metal contamination leads to a serious impact on the human society and eco system. The environmental remediation technologies play an important role in the recent era. I (the author) have been developing several heavy metal detection and analysis systems (Continuous Research) in my previous research, and I wished to develop or utilize a new material as an adsorbent in order to recover the environment. (Fig.1)

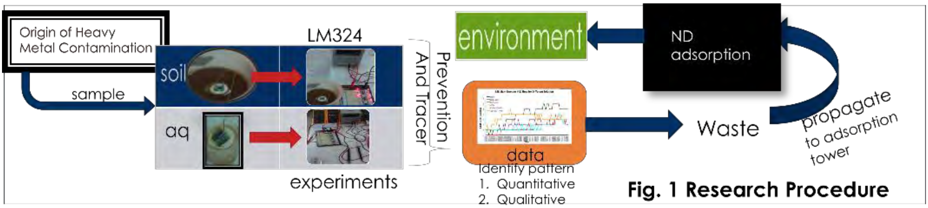


Fig. 1 Research Procedure

During last years' vacation, I am fortunate to have the opportunity to work on a research project "Biological Tracing and investigation of Utricularia Gibba's Digestion System by Fluorescent Nanodiamonds (FNDs)", and found that Nanodiamonds (NDs) have strong adsorption ability on plants. After several literature reviews, I found the carbon allotropes may hold the key to enable a "GREEN" future including biocompatibility, and reusability, which reflects that NDs may be a good adsorbent for heavy metal removal!

B. *Objectives*

Engineering Aspects

1. Developing high-efficiency adsorbent for the removal of heavy metal ions
2. Manifesting the biocompatibility and reusability of the adsorbent

Scientific Aspects

1. Understanding the adsorption mechanism and make further experiments for manifesting

II. Scientific Problems and Questions

Engineering Problems

1. It is crucial to find an adsorbent which can achieve high atom economy (high removal of heavy metal ions).
2. Nano particles (NPs) as a heavy metal adsorbent was not prevalent before due to the cytotoxicity of other NPs.

Scientific Questions

1. Investigate whether the Acidified Nanodiamonds has carboxylate group and are able to adsorb heavy metal ions.
2. If so, what is the adsorption mechanism of Nanodiamonds?

III. Instrumental and Experimental

A. Experimental Instruments and Sample Preparation

- **Scanning Electron Microscope (SEM) and Electron-Dispersive X-ray Spectroscopy (EDX)**

Field Emission Scanning Electron Microscope (NOVA NANO SEM 450, Fig.2b) is used in this research for surface morphology imaging. The basic principle for SEM is based on the reflection of the electron which is shot by the electron gun [powered by the magnetic field] (Fig.2a). The types of signal include Secondary Electron (SE) [Secondary means that the electron is not the primary electron (the electron emitted)], Backscattered Electron (BS)[the opposite motion of the incident electron], and X-Ray reflection (X-Ray) by different angle and orientation. The SEM image is due to the measurement of the SE's reflection angle. The EDX analysis is based on the energy radiation for filling the hole.(Fig.3) The sample were dried, put on the carbon paste, and covered with platinum

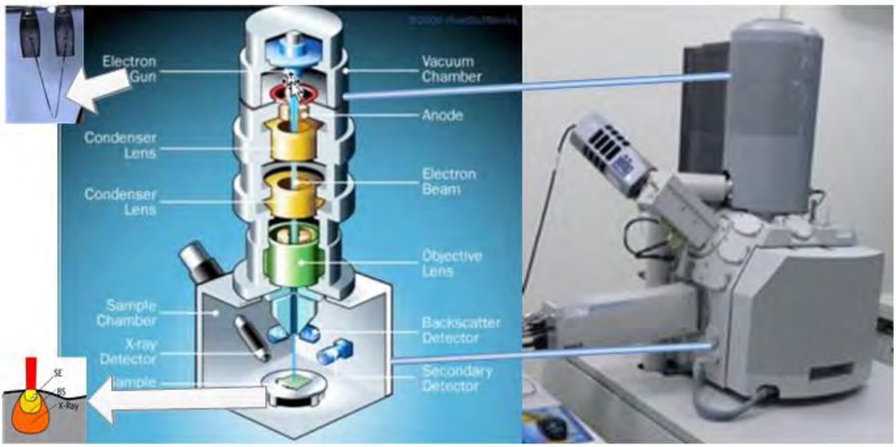


Fig.2 SEM (a) Explanations[4] (b) NOVA NANO SEM 450

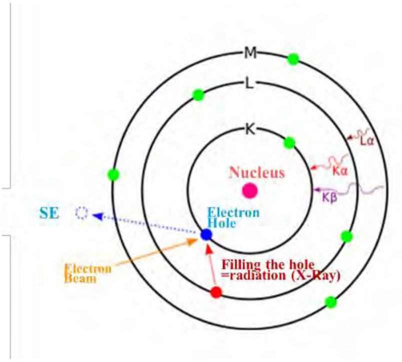


Fig.3

Simple Explanation for EDX spectroscopy

➢ Confocal Microscope

The basic principles of a Confocal Microscopy is to detect the light which is reflected from the sample. If we need to look in the fluorescent (for instance, in biocompatibility research, we utilize this technique for tracing), the light emitted can be controlled in several wavelength. In this research, confocal imaging was carried out using a SP5 inverted microscope (Leica) equipped with three solid-state lasers operating separately at 561nm for the excitation of FND. The bladder traps on the *Ultracularia Gibba* were made into water treated specimen.

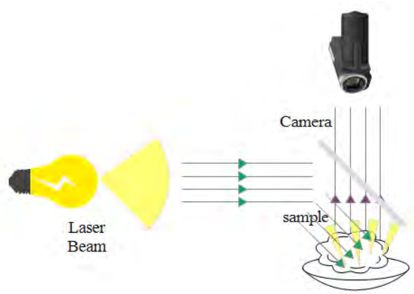


Fig.4

Laser Beam Confocal Microscope

➢ Inductively Coupled Plasma Mass Spectroscopy (ICP-MS)

The basic principles of ICP-MS is by using ICP to ionize, and utilize different engineering skills (Ex: Let ions collide with helium to decrease impurities, or by using different charges to separate targeted ions) to filter the impurities (Fig.5). In this study, we prepared different standard solution (Pb^{2+}, Cu^{2+}, Ni^{2+}, and Co^{2+}) with 6 concentrations (0 ppb, 10 ppb, 20 ppb, 30 ppb, 40 ppb, and 50 ppb) for drawing the calibration curve, and dilute sample into range 0 ppb - 50 ppb for ICP-MS (Aligent 7700) measurement.

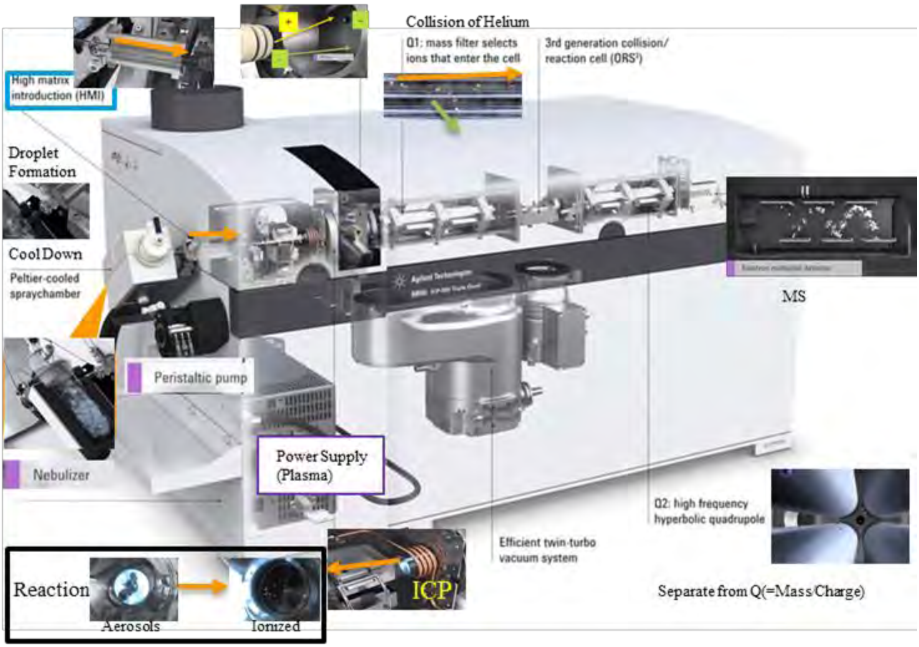


Fig.5 An Illustration of The ICP-MS [1][8]

- **Fourier Transform Infrared Spectroscopy (FT-IR) and Ultraviolet Visible Spectroscopy (UV-Vis)**

Both spectroscopy measure the transmittance amount after penetrating the sample. The data were gained in transmittance (%) or absorbance [(100-transmittance)%], and I was able to convert PRN file into excel and draw diagram by ourselves. Before measurements, it is necessary to dry the sample (NDs) and add potassium bromide (ratio of sample and KBr=0.2%-1%) to enhance the transparency of the sample. The measured range of FT-IR falls on 700 cm^{-1} to 4000 cm^{-1}. UV-Vis sample is placed in a small column and putted in the UV-Vis spectroscopy. In order to get accurate concentration (Optimized Conditions' Experiment: Co^{2+} analysis), standard solution (0, 200, 400, 600, 800, and 1000 ppm Cobalt Nitrate) are tested for calibration. The wavelength range which are proportional to the Co^{2+} concentration falls in 510nm-515nm.

- **Zeta Potential Analyzer**

By looking at the dynamic scattering pattern (Fig.6), the Zeta Potential Analyzer is able to measure the size distribution of the particle. In the optimized condition – pH influences experiment, this instrument (Zetasizer-3000HS, Malvern) is used for identifying the zeta potential changes among different value.

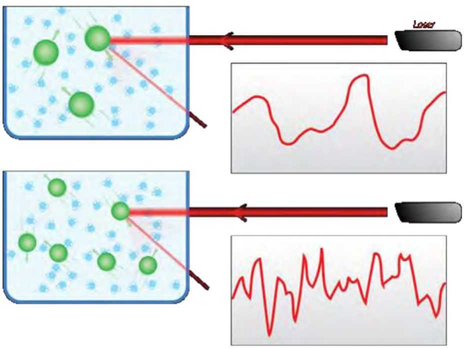


Fig.6

An Illustration of the Influences by the Particle Size Distribution [10]

B. Preparation of Nanodiamonds and Surface Modification

➢ Introduction to NDs production

Plasma Enhanced Chemical Vapour Decomposition (PECVD), detonation, High Pressure High Temperature (HTHP) process…etc. are usual routes for NDs production. The main idea for these methods are by making the precursors (Ex: PECVD, detonation process add methane. HPHT process uses the carbide on the surrounding.) discrete into single elements and go through the nucleation process to make precipitates (Fig.7A)

In this study, NDs (Micron+MDA, Element Six) were produced by HPHT process by adding high pressure (30 GPa) on two carbide anvil and making temperature differences (5-30 celcius) on both carbide anvil (upper carbide: 1500 K) (Fig.7B).

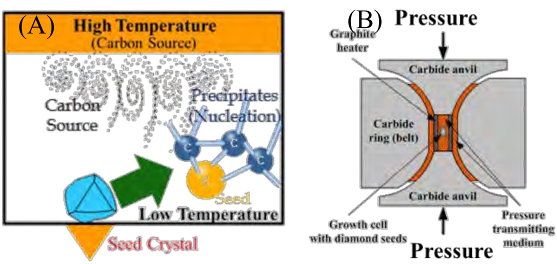


Fig.7 HPHT process

(A) A simulation of the NDs production

(B) HPHT instruments [3]

➢ Introduction to FNDs production

1. Turn NDs into FNDs : [Ion irradiation]

Use Ion beam to add helium into the NDs structure, and make carbon into nitrogen. After making a C-N-C structure, annealing is used to remove carbon and make N-V (V for vacancy), producing Ion-irradiated FNDs. In the biocompatibility experiment, FNDs were produced by radiation damage of type Ib diamond powders

(Micron + MDA M0.10, Element Six) using a 40 keV He^{2+} ion beam, followed by thermal annealing at 800 Celcius, air oxidation at 450 C and purification in concentrated H2SO4–HNO3 (3:1, vol/vol) solution at 100 Celcius.

2. Produce NDs:

   Add Nitrogen in the production (PECVD, HTHP) of NDs, in order to make the nitrogen in diamond structure naturally.

- **Preparation of Acidified Nanodiamonds (ANDs)**

1. Acidified Process (Fig.8)
   1) Nanodiamonds were synthesized by high pressure high temperature process [30 GPa, 1500 K].
   2) Acidified Nanodiamonds were prepared by treating the nanodiamond with nitric acid (2M) and sulfuric acid (2M) for three hours.

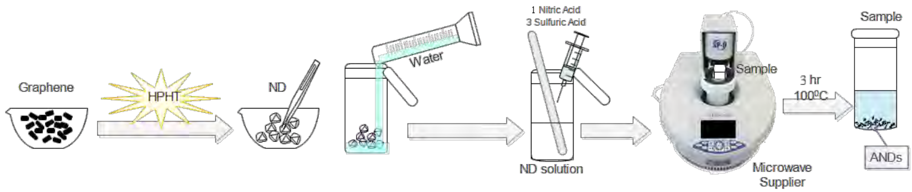


Fig.8 An illustration of the ANDs producing process

2. Expected Results: ND-COOH functional groups
3. The results were characterized by SEM and IR spectroscopy.

C. Adsorption Process and Mechanisms

The adsorption experiments focused on four divalent metal ions (Pb^{2+}, Cu^{2+}, Ni^{2+}, and Co^{2+}), the environmental conditions were under 300K 0.5 mg/ml ANDs solution. The morphology and surface characterization were under research by SEM and FT-IR respectively.

D. Green Chemistry Concepts

- **Biocompatibility:**

  Utricularia gibba, a shallow water vegetation, were used to test the biocompatibility of ANDs by adding FNDs in algae, and the bladder traps of the algae have been taken for investigation under confocal microscope.

- **Reusability:**

  The used NDs (AND-M^{n+},M^{n+} for metal ions) were treated with nitric acid. The functional groups of washed ANDs were investigated by FT-IR, and the adsorption efficiency was measured by UV-Vis.

IV. Results and Discussion

A. ANDs Characterization

Two criteria were used to analyze the characterization of ANDs.

1. SEM:

The size of ANDs aggregate was found between 80-100 nm (Fig.9).

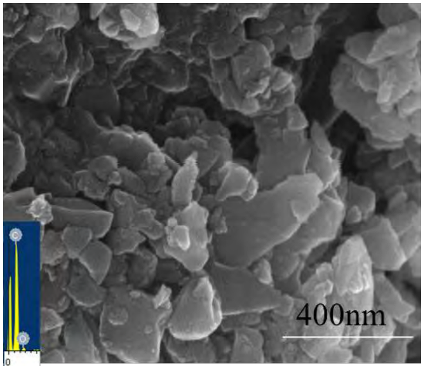


Fig. 9 SEM Image of Nanodiamond Aggregation

2. FT-IR Spectra: (Fig.10)

(1) Our expected results (ND-COOH) are identified.

(2) ANDs also possess nitro groups.

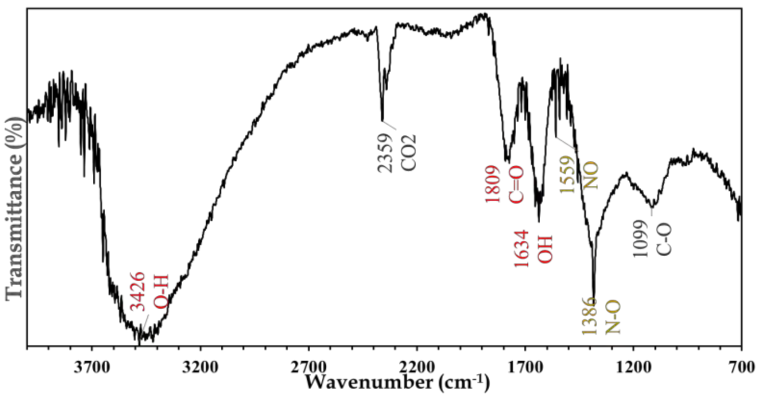


Fig.10 FT-IR spectrum of ANDs

B. Adsorption Experiments (Fig.11)

(1) ANDs have high efficiency towards Co^{2+}.

(2) Adsorption amount increases with the initial concentration.

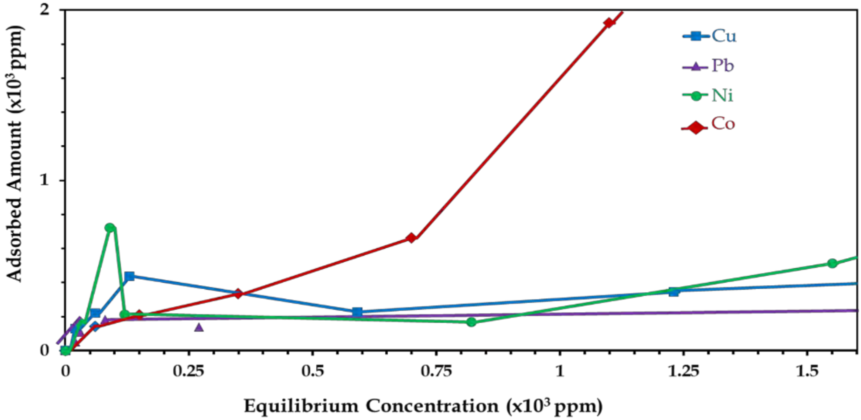


Fig.11 Adsorption Curves of Co^{2+}, Cu^{2+}, Ni^{2+}, Pb^{2+}

C. Adsorption Mechanism

1. SEM image of AND-M^{2+}

(1) After adsorption, SEM shows that ANDs' single particle (Fig.12A-C) are smaller than the original ones (Fig.12D).

(2) The ANDs – Co^{2+} is highly aggregated compared to other ANDs – M^{n+}.

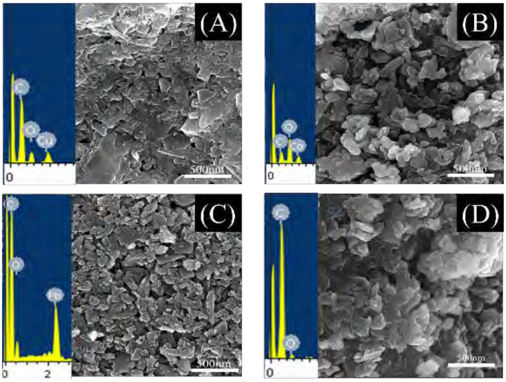


Fig.12 SEM images of ANDs-M^{n+}
(A) Co^{2+}
(B) Cu^{2+}
(C) Pb^{2+}
(D) Control

(3) We posed one hypothesis

A. ANDs will re-disperse after adsorption, enhancing the adsorption capacity [result in IV. B]

B. The higher adsorption capacity ANDs – M^{n+} domains, the more aggregated nanodiamond morphology it reflects.

We can assume if we add higher [M^{n+}] in solution, which results in extremely high adsorption capacity, the nanodiamond is going to be more aggregated. (IV. C. 4.)

2. EDX spectra of AND-M^{2+}

EDX spectra (insets to Fig. 12) confirm the adsorption of Co^{2+}, Cu^{2+}, and Pb^{2+}.

3. FT-IR spectroscopy of AND-M^{2+}

(1) Disappearance of the CO peaks and broadening of OH peaks reveal the coordination of M^{n+} with carboxylate group. (red region in Fig.6)

(2) Due to the Co^{2+} - NO_3^- interaction, no repulsion occurs between ANDs (yellow region in Fig.6) and

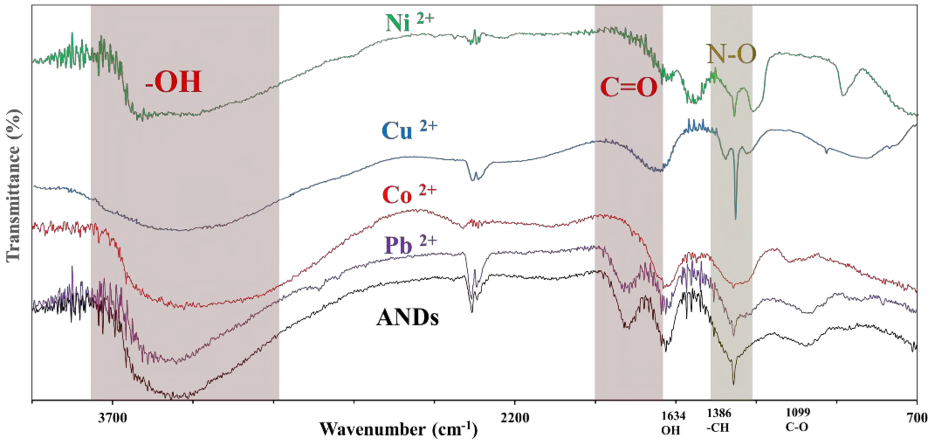


Fig.13 FT-IR spectra of ANDs-M^{n+}

4. AND-Co^{2+} Morphology by SEM (Fig.14)

Three concentration (500ppm, 5000ppm, 50000ppm) of Co^{2+} are added into ANDs solution to test if the hypothesis we posed (**IV. C. 1. (3)**) is right.

(1) The higher [Co^{2+}] is concentrated, the smaller ANDs particle is observed.
(2) The higher [Co^{2+}] is concentrated, the more aggregation phenomenon is observed.

We proved that our assumption is right!

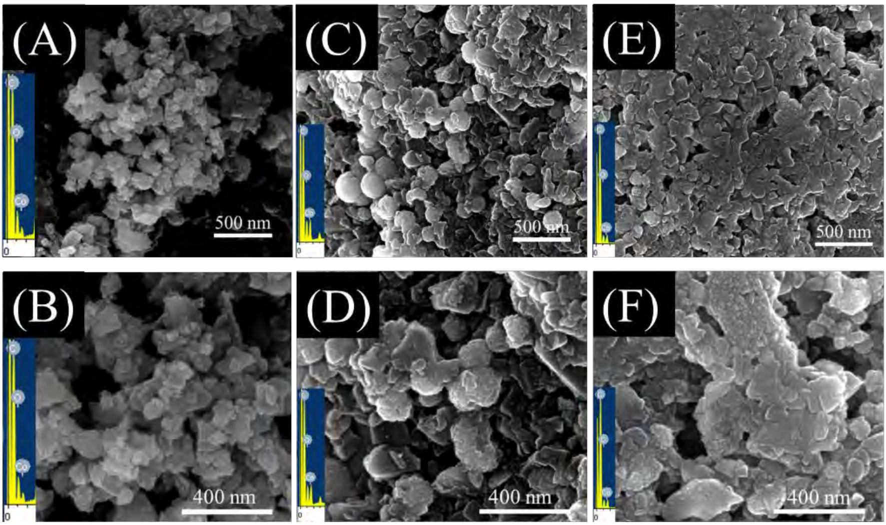


Fig.14 SEM images of ANDs-Co^{2+}

Cobalt Nitrate Concentration: (A)(B) 500ppm (C)(D) 5000 ppm (E)(F) 50000 ppm

D. Optimized Condition for Adsorption

1. Equilibrium Time

Removal efficiency of Co^{2+} reaches maximum values after 20 min. (Fig.15)

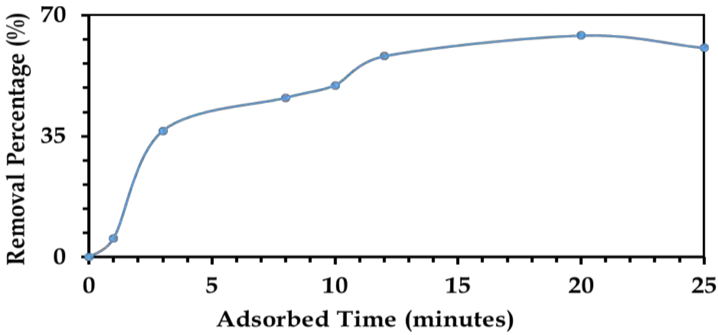


Fig.15 Kinetics of Co^{2+} Adsorption

2. pH influences

Adsorption capacity enhanced with increasing pH value from pH 2.50-4.00. (Fig. 16)

At pH value greater than 3.00, negative charge on the surface of ANDs were observed, thus the interaction with Co^{2+} increased.

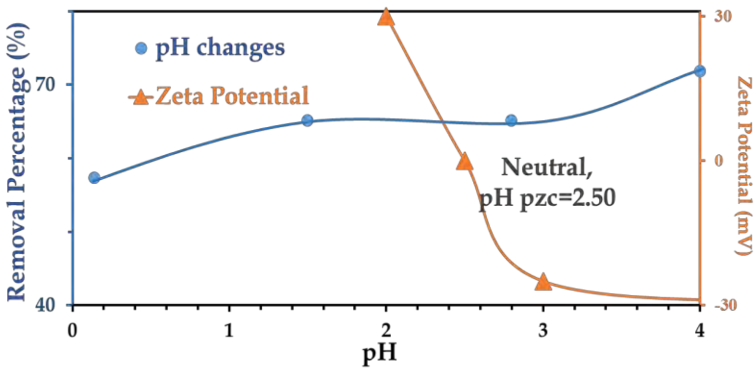


Fig.16 Zeta Potential and Co^{2+} Adsorbed Amount With Their Correspondence

3. Adsorbent Quantity

The maximum adsorption occurs at 0.25 mg/ml of ANDs solution.

The Co^{2+} adsorption capacity increases with amount of ANDs from 0.06 to 0.25 mg/ml. Further increase of the ANDs dosage did not substantially increase the adsorption of Co^{2+}.

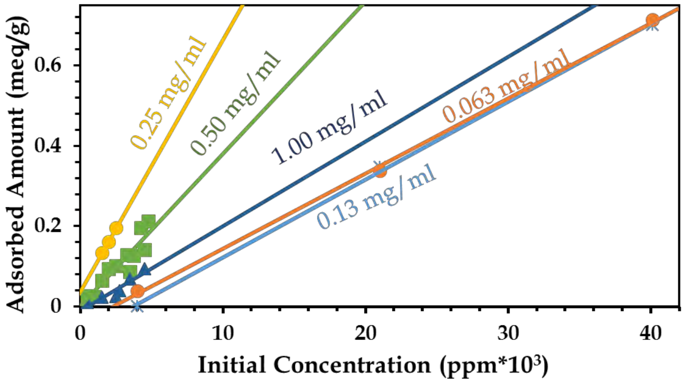


Fig.16 Effect of ANDs Amount on Co^{2+} Adsorption as a Function of ANDs Initial Concentrations.

4. Temperature Effects

Though the adsorption process is endothermic, the temperature effect is not significant. (Fig.17)

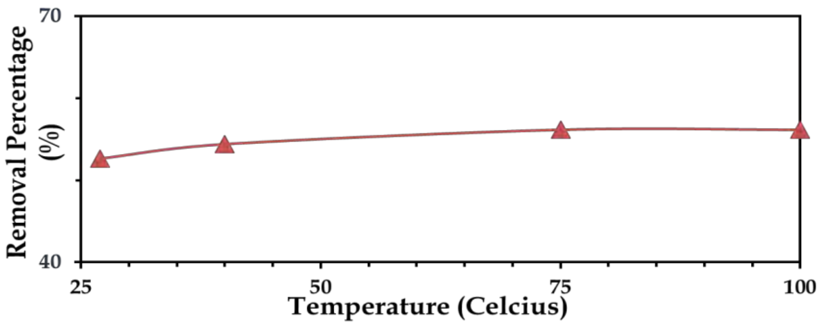


Fig.17 Temperature Effect on Co^{2+} Adsorption

E. Green Chemistry Concepts

1. Biocompatibility

Though the FNDs were adsorbed in the stem of *Utricularia gibbas* (Fig.18A,B), the activity of microorganisms was not affected by FNDs(Fig.18C).

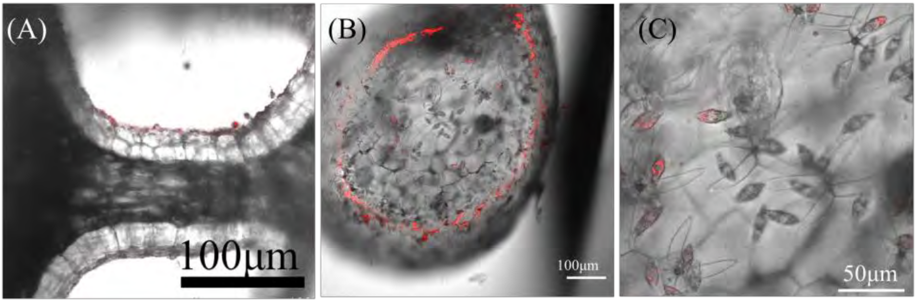


Fig.18 Confocal Microscope Images of FNDs Treated Bladder Traps

(A) *Utricularia gibbas'* stem (B) *Utricularia gibbas'* bladder trap

(C) Viable microorganisms in *Utricularia gibbas'* bladder trap

2. Reusability

(1) The observation of CO functional group indicated that ANDs were regenerated after treating with nitric acid (Fig.19).

(2) The adsorption capacity was retained after regeneration (Fig.20).

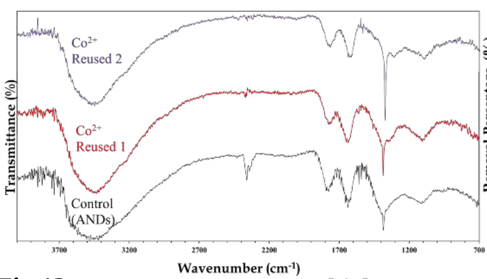


Fig.13 FTIR Spectroscopy Which Reflects the Surface After Regeneration

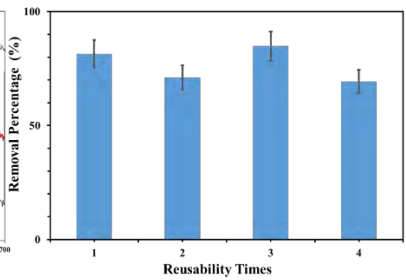


Fig.14 Reusability Chart

V. Conclusions

1. **Surface carboxylate functional group is the key factor for heavy metal removal.**
2. **ANDs are effective adsorbents for Co^{2+} removal, probably due to the interaction of NO_3^- ions.**
3. **A special re-dispersion and aggregation phenomenon were observed in this research.**
4. **The optimized condition for Co^{2+} adsorption was found to be pH>2.5, 20 minutes adsorption time, and at 0.25 mg/ml of ANDs.**
5. **ANDs are biocompatible and reusable, meeting the criteria of Green Chemistry**

VI. References

1. Agilent Technologies Announces Launch of the World's First Triple Quadrupole ICP-MS. Retrieved: May Seventh 2015 From:http://www.measurementest.com/2012/01/agilent-technologies-announces-launch.html
2. A. M. Schrand, H. Huang, C. Carlson, J. J. Schlager, E. Ohsawa, S. M. Hussain, and L. Dai. Journal of Physical Chemistry B 111 (2007) 2-7
3. Diamond Synthesis by HPHT Process. Retrieved: May Seventh 2015 From :http://www.substech.com/dokuwiki/doku.php?id=synthetic_diamonds
4. How a Scanning Electron Microscope Works? Retrieved: May Seventh 2015 From: https://www.youtube.com/watch?v=VWxYsZPtTsI
5. M. Hadavifara, N. Bahramifar, H. Younesi, Q. Li. Chemical Engineering Journal **237** (2014) 217–228.
6. O. Shenderova, A. Koscheev, N. Zaripov, I. Petrov, Y. Skryabin, P. Detkov, S. Turner, and G. Van Tendeloo. Journal of Alloys and Compounds **115** (2011) 9827–9837.
7. T.A. Dolenko, S.A. Burikov, K.A. Laptinskiy, T.V. Laptinskaya, J.M. Rosenholm, A.A. Shiryaev ,A.R. Sabirov, I.I. Vlasovf. Journal of Alloys and Compounds **586** (2014) 436–439.
8. The Principles of ICP-MS Retrieved: May Seventh 2015 From: https://www.youtube.com/watch?v=MQqtV2oiC6U
9. V. N. Mochalin, O. Shenderova, D. Hoand, Y. Gogotsi. Nature Nanotechnology **209** (2011) 11-20.
10. Wikipedia: Dynamic light scattering. Retrieved: May Seventh 2015 From:http://en.wikipedia.org/wiki/Dynamic_light_scattering

11. Y.R. Chang, H.Y. Lee, K.C, C.C Chang, D.S. Tsai, C.C F, T.S. Lim, Y.K Tzeng, C.Y. Fang, C.C. Han, H.C. Chang, W. Fann. Nature Nanotechnology **3** (2008) 284 – 288

【評語】120001

本實驗以奈米鑽石進行水中重金屬離子吸附實驗，由於奈米鑽石之表面功能甚多，有助於加強水中重金屬離子之吸附，本研究實驗完整且考慮其重複再利用可行性，是一個具有創意完整的研究。